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with which is incorporated

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Founded in 1864 by the late Dr. Henry Woodward, F.R.S.

Edited by

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and

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OR

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THE
GEOLOGICAL MAGAZINE
VOLUME LXXV.

No. I.—JANUARY, 1938.

ORIGINAL ARTICLES.

Quaternary Conditions in Malta.

By C. T. Trechmann.

(PLATES I and II.)

TO compare a rising island (Barbados) with one supposed to be sinking (Malta) two visits were paid to Malta and Gozo in 1933 and 1936 of four and six weeks' duration. One is soon convinced that a good deal is yet to be learnt about these islands, especially as regards the later deposits. The Pleistocene beds of the Maltese islands occur as a number of separated deposits and can be classified into :—

1. Valley loams and breccias, often partly washed out again by streams or by the sea.
2. Conglomerates and breccias bordering or near the sea coast, often thinning out as calcareous veneers.
3. Ossiferous deposits in caves and fissures.

These beds vary no doubt in age, but the considerable antiquity of most of them is indicated by their occurrence as isolated patches widely separated by later erosion.

A great deal has already been written on Malta, so that it is not easy to avoid repeating matter already published. The more novel features in this paper are the idea that the reddened and blackened pebbles, so conspicuous in the Quaternary conglomerates, are the result of a scorching and arid period; and the recognition of a faunule of extinct species or varieties of land shells.

The solid formations of Malta and Gozo are as follows, the correlation being mainly after Dr. F. A. Bather :—

Upper Coralline Limestone.

White limestone Reddish yellow limestone Soft white limestone	Tortonian, Upper Miocene.

Greensands.

Yellow sand Black sand	Helvetian, Middle Miocene.

Blue clay (= Schlier).

Globigerina Limestone.

White rotten limestone Hard-grained limestone	Burdigalian.
Semicrystalline limestone Yellowish soft limestone	Aquitanian.

Lower Coralline Limestone.

Scutella bed Hard compact	Tongrian, Oligocene.

Recently (1928) Mr. C. Rizzo[1] has published a more detailed lithological enumeration of the different beds together with an up-to-date description of the various fault systems that have influenced the structure of the islands; unfortunately without a map as yet.

Apart from a general slight inclination to the north-east, the rocks have been thrown into gentle undulations, the only considerable dips being in the vicinity of, and chiefly on the downthrow sides of, some of the faults. The faults, or systems of step faults, sometimes take the form of sinuous sloping dislocations rather than straight vertical fractures. The line of weakness that induced the faults seems in some cases to have been influenced by solution cavities, and the fault tends to divert itself into semi-amphitheatre-like embayments, down which the higher beds have been depressed on strongly slickensided slopes, for instance at Cala Dueira in Gozo. Mr. Rizzo (*op. cit.*, p. 28) notices that the slickensides in some of the Gozo faults are not vertical but are inclined or nearly horizontal, and infers from this that there have been "considerable lateral displacements". In another case he says the slickensides within a length of a few hundred yards change their direction from approximately vertical to nearly horizontal.

These features have given rise to the curious term "circular faults" in Maltese publications, and this is applied to a surprising phenomenon called the Makluba. This is situated just south of Krendi, near the south-west coast of Malta. It is a vertical-sided circular depression, looking like a gigantic pot-hole, 100 feet deep and 200 feet across, with a small waterworn gully leading into it on the south-west side. It has been noticed by several writers, but recently Professor J. Borg[2] has compared it with the Doline of Istria. He says after a heavy rain the water in the Makluba fills the whole cavity almost to the brim, but in a few days it drains off again, presumably into lower cavities. He compares the Makluba with other so-called "circular faults", which are in reality part-circular fault deviations, at Marfa, as well as at Dueira in Gozo;

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[1] *Report on the Geology of the Maltese Islands*, Malta, Govt. Printing Office, 1932, 5–37.

[2] "Traces of the Quaternary Ice Age in the Maltese Islands," *Archivum Melitense*, vol. x, No. 1, 1936, 7–16.

the Fungus Rock off the coast at Dueira; and with features on the west side of the small island of Comino. Some of the faults have moved in Quaternary times; at Malak some masses of red Quaternary crushed conglomerates adhere to the slickensided fault plane a little above sea level. The Grand or Great Fault of Malta passes across the island in a N.E.–S.W. direction from the north-east shore at Madalena Tower to Fomm-ir-Rih Bay on the west coast. The upcast edge of the fault seems to have risen at the same time as streams such as that in the Wied il Ghazel cut their way down. This stream, or its continuation, after starting in a wide open valley, suddenly cuts a deep gorge through the uprisen edge of the Lower Coralline Limestone and then continues its way on the flat ground towards the marshes of Salina Bay.

The high western side of Malta has apparently risen as the down-faulting off the coast took place. The famous harbours of the east and south-east coast are partly drowned systems of sub-aerial erosion. Rizzo (*op. cit.*, p. 26) mentions in support of this that "during the laying of foundations of a breakwater, the divers detached some pieces of stalagmites from the sea bottom at a considerable depth, which stalagmites could not have been formed under water". The oft-quoted prehistoric cart-tracks that run to the edges of cliffs, or down to a harbour, reappearing on the opposite side of the water, are evidence of erosion of the cliffs or depressions of the land since human times.

RED AND BLACK LIMESTONE PEBBLES IN THE QUATERNARY BEDS.

The Pleistocene deposits of Malta and Gozo, except those in the caves, are more or less highly charged with limestone pebbles of a red, pink, grey, or black colour. These pebbles have puzzled many observers; J. H. Cooke[1] for instance writes: "Another remarkable feature of this Pleistocene bed is the extraordinary quantity of black limestone pebbles that occur in it. Notwithstanding a diligent search in the district I was unable to discover any traces of a formation partaking of the lithological characteristics of these pebbles, to which they might have been referred." These pebbles had also previously been noticed by Leith Adams[2] as "apparently quite distinct from any varieties of the native rocks".

For some time I was mystified by them, especially as there were rumours that the red limestone was Mesozoic Apennine limestone and that the black pebbles were volcanic. However, the mystery was solved (for me) when I observed, first at Benghiza Gap, that the surface of the bed rock where the conglomerate was in process of being eroded away was similarly reddened and blackened, only, however, to a very small depth.

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[1] "Geological Notes on Gozo," GEOL. MAG., XXXVIII, 1891, 352.

[2] *The Nile Valley and Malta*, 1870, p. 151.

The long continued action of the sun seems to have an effect like that of actual burning in a fire, and the masses of red and grey scorched stones in the conglomerate at Benghiza, for instance, look as if they had lain in a gigantic hearth. One can observe in single pebbles, as well as on the underlying rock surface, a transition from yellow unaltered limestone, through shades of red and grey, to black. In some pebbles the interior has shrunk, leaving a hardened, sometimes crackled or expanded, outer layer, suggesting in appearance a bread-crust volcanic bomb. In the case of pebbles of the coarse Lower Coralline Limestone the blackening has sometimes affected the matrix, leaving the fragments of crystalline echinoderm remains still white.

The condition is certainly curious and merits further investigation. The reddening may be a process of incipient lateritization, but the black colour is apparently due to carbonaceous matter. Dr. J. A. Smythe kindly tells me that there is only the merest trace of manganese in a specimen of a red and black pebble I sent to him, and that the black matter is bituminous in nature.

Examination of thin slices of these rocks shows, in the case of a very black pebble, the limestone unaltered but smudged and clouded by an impregnation of the carbonaceous matter, while a slice of a reddened pebble shows specks of ferruginous matter scattered among the sections of foraminifera and other organisms.

These scorched-looking pebbles, together with the conspicuous red clayey matrix of the Quaternary breccias and conglomerates, point to an intensely arid condition during some part of Pleistocene times, and doubtless this had an influence in exterminating the vertebrate fauna.

Some of the tops of the flat hills in Gozo are strewn with red and black limestone fragments, apparently weathered relics of the surface of the rock scorched during this arid period.

The absence of red and black limestone among the pebble beds in the caves, for instance in Ghar Dalam or in the small cave above the Wied el Ghazel, seems to imply either that the caves were filled in before the arid conditions took effect on the rocks, or that the pebbles were all derived from the interior of the cave and not washed in from outside. It would seem that the first explanation is the more likely one.

Some reddening of the limestone in Malta, however, is due to other causes than arid scorching. Mr. Rizzo, not being entirely satisfied with my explanation of the phenomenon, referred to a locality near the bottom of the Wied id Dis, near Gargur, where the rock has been altered to a dark red colour to a considerable depth. Dr. Baldacchino and I visited the locality; the rock is coloured a dark red or brown in vein-like masses, but after seeing the material *in situ* and after examining a slice of it one concludes that it is due to a local impregnation with ferruginous matter and that it differs from the red, surface-altered, pebbles in the conglomerates.

PROBLEMS OF THE LAND BRIDGES.

Gozo is about 50 miles distant from Sicily. The channel between Malta and Sicily is less than 600 feet deep, and becomes in places as shallow as 125–150 metres. Between Malta and Africa an upheaval of 200 fathoms would render the connection with Tripoli dry except for one or two narrow channels.

L. Soós[1] concludes that the living " malaco-fauna of the Maltese islands is a mere appendage of that of Sicily ", and " Malta's mollusc fauna does not contain any African elements ". This may be reasonable enough for the living land shell fauna, which is an impoverished one, but the newly-found fossil fauna leads to somewhat different conclusions and shows species recalling African as well as Sicilian forms.

R. Vaufrey's[2] investigations indicate that the three species of Maltese pygmy elephants, the smallest of which is less than a metre high, are dwarf races of *Elephas antiquus* and are European and not African elephants.

It seems probable that Malta has been joined to Africa as well as to Sicily, but that the junction with Africa was separated earlier than that with Europe.

FISSURES.

Fissures, chiefly in the Globigerina Limestone, have often proved to be rich in bones; the latest one to be examined is the Tal Gnein[3] fissure, near Mqabba. It contained a quantity of remains of the Giant Tortoise and other species of *Testudo*, various other vertebrates, including a large new Mustelid, *Nesolutra euxena* Bate; the Giant Swan, *Cygnus falconeri*, etc.; but yielded no land shells. It is considered to be a very early fissure on account of the occurrence of so many *Testudo* bones.

None of the fissures seem to go very deep down; the Tal Gnein is 95 feet long, 2 ft. 10 in. wide, and tapers to a mere crack at a depth of 20 feet. Its direction is N.E.–S.W. Fissures are not seen in the deep cuttings of the Globigerina Limestone in the fortifications on the west side of Valletta, but I observed several small ones in the same rock on the shore below St. Elmo Point, Valletta. They run more or less east and west, and are generally vertical and about 1–2 feet wide, but string off into mere red threads. The contents are mostly very dark red in colour, but at the sides there is often a layer of grey calcareous travertine-like material with tubules or matted branching structures evidently vegetation, but nothing identifiable. These fissures go down below sea level, and in one

[1] " A Systematic Zoogeograph contribution to the Mollusc Fauna of the Maltese Islands and Lampedusa," *Archiv. für Naturgeschichte*, N.F., Bd. 2, Heft 3, 1933, 305–353.

[2] *Archives de l'Institut de Pal. Humaine*, Mem. 6, 1929, 1–220.

[3] J. G. Baldacchino, *Ann. Report Museum Dept. Malta*, 1933–4, p.xxv, and 1935–6, p. xxxi.

I collected *Helix protovermiculata* (?), *Rumina decollata*, and *Clausilia bidens*, but all broken specimens; and in another a piece of deer tooth. The sides of these fissures have been weathered and pitted before they were filled in, and though they plunge below sea level they are entirely of terrestrial origin.

QUATERNARY SECTIONS IN MALTA.

Mghalak or Malak. Pl. II, fig. 2.

The great Malak fault, which must have a throw approaching 600 feet, cuts a slice off the south-west coast of Malta and extends for about 5 miles in a W.N.W.–E.S.E. direction, bringing Upper Coralline Limestone down more than 200 feet below the top of the Lower Coralline Limestone. The fault line is sinuous, the face slopes steeply seawards, and is strongly slickensided. Here and there patches of crushed Quaternary conglomerate are seen adhering to the fault face, having apparently been deposited in fissures formed by the fault and crushed by later movements of it.

The sketch of the locality in Suess [1] is taken from Adams.[2] At the top of the cliff, north-west of the Mnaidra prehistoric temple, was the Malak cave or fissure of Adams, which yielded many bones, but is now quarried away. In a new quarry near by, however, there remains a mass about 5 feet long and 3 feet thick of red and brown breccia with lumps of phosphatic rock, reddened limestone, and lateritic material. A cluster of land shells, mostly small specimens of *Helix bateae*, but also *H. zammiti* and *Clausilia* sp., occurred and among them two teeth of the giant dormouse, *Myoxus*, and fragments apparently of *Hippopotamus* teeth and bird bones.

Along the base of the fault slope near the sea another and more extensive series of Quaternary beds occurs. Adams records a number of animal remains, but Dr. Baldacchino and I saw no trace of bones. J. H. Cooke,[3] however, says the Malak beds admit of a tripartite division and he found a humerus of elephant in beds to the left of the mouth of the Wied el Mirhla. At one place about 25 feet of conglomerate rests on the steeply dipping edges of the downfaulted Upper Coralline Limestone. They consist of alternating beds of large fragments and of red pebbly laterite material; they rest horizontally but also in some places pass down into vertical cracks and fissures. These beds are full of reddened and blackened limestone pebbles in all stages of alteration. The less pebbly red matrix contains land shells, but crushed and difficult to identify. *Rumina decollata* occurs, with apparently *Helix bateae* and *H. protovermiculata*.

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[1] *The Face of the Earth* (Engl. translation), vol. i, p. 349.
[2] *The Nile Valley and Malta*, 1870, pp. 145 and 174.
[3] GEOL. MAG., XLIII, 1896, p. 205.

Marfa Ridge. Pl. II, fig. 3.

The north end of Malta, the Marfa Ridge or Peninsula, shows some interesting Quaternary beds. At the north-west extremity or Marfa Point the rock surface slopes gently to the north-east in the direction of the small island of Comino, and has an irregular, apparently waterworn, possibly seaworn, surface scorched and reddened in places under the conglomerates. There is some indication of this rock surface having been bored by marine organisms, but I could not decide with certainty whether this was the case. The following beds occur lying on it:—

1. A bed of consolidated sand rock, 3–5 feet thick; it cannot be regarded as a raised beach, but it looks like an old dune bed of calcareous sand. It contains many small worn fragments of marine shells, especially Gasteropoda; *Cerithium, Dentalium, Pleurotoma, Nassa*, etc. The commonest fossil in it is *Helix baldacchini*, which occurs quite fresh and well preserved, along with other land shells. This dune rock is evidently connected with the red conglomerate below, and is not much newer in age, as at one place a lens of conglomerate lies in the sand bed a foot or two above its base.

2. Red conglomerate and marl, up to 12 or 15 feet thick, containing large and small pebbles, many of them angular, reddened or blackened. The matrix contains land shells here and there; *Rumina decollata, Helix protovermiculata, H. baldacchini* (rare), and clusters of the small angulated *Xeroclivia*-like forms.

These two beds continue down to and below sea level to the north-west, but to the south-east they rise up the edge of the cliff to a height of about 80 feet, but at this height they weaken and the dune rock becomes attenuated and indistinct. This points to a tilting process having occurred at the north-west corner of Malta. On the south side of the adjoining Chirkawa Bay, at about 100 feet above sea level, a small old valley has been filled in with red conglomerate, evidently at one time continuous with that at Marfa point, a third of a mile to the north. The bay has been eroded by the sea since the Quaternary beds were formed, and this is one of the places where the prehistoric cart tracks go to the edge of the cliff and disappear, the cliff having fallen away in human times.

A little west of the landing place of the steamers for Gozo another patch of red conglomerate is seen a few feet above sea level, and above it a thin layer of consolidated dune sand. Land shells here include *Helix protovermiculata, Mastus pupa*, etc.

A mile east of the landing stage in the inner angle of Armier or Ahrmar Bay the surface of the Upper Coralline Limestone has a scorched appearance and on it rests a bed of red clay about 5 feet thick, containing pebbles and stones, overlain by 3 feet of dune rock. The exposure extends inland southwards up the gently sloping coast for some 50 yards, where it becomes a mere calcareous veneer. At places the dune rock takes on a sort of travertine structure, with hollow calcareous casts of stems and branches of matted vegetation looking like brushwood. Fossil land shells are well preserved and include *Helix baldacchini*, *H. zammiti*, *Clausilia bidens* (rare), etc.

Half a mile south of Armier Bay on the north coast of Melleha Bay a conspicuous patch of Quaternary beds some 15 feet thick is seen. J. H. Cooke collected some Helices about 1892 at this locality, namely " E. of Battery on N. side of Melleha Bay ", these are now in the British Museum, Natural History ; among them are specimens of *H. baldacchini*. The red clayey conglomerate at the base is 3–4 feet thick and is full of red and black limestone fragments ; this is overlain by a representative of the dune rock, 2–3 feet thick, and above this comes some 5 feet of red clayey conglomerate, with a few black pebbles. The few land shells I saw were very crushed or broken.

No bones were noticed in the Marfa area, and around the edges of this northerly ridge of Malta is the only locality where I have seen the consolidated bed of dune sand. The occurrence of this old dune bed with worn marine shell fragments indicates that the northern peninsula of Malta cannot have been very far from the sea shore during the part of Quaternary time that it represents. The Marfa Block rises to 400 feet at its south-west corner, and has been tilted rather than uniformly depressed.

St. Paul's Bay.

Quaternary conglomerates occur on both the north and south sides of this bay and the presumption is that they were once continuous and the sea came in and divided them. On the north shore a short distance from the traditional site of St. Paul's shipwreck, the place where " two seas met ",[1] separating a small island from the mainland, is the only locality, a few hundred square feet, where the curious sculptured spiral *Clausilia scalaris* lives. It has not been found in the fossil state.

Half a mile south-west of this, still on the north shore, some red Quaternary conglomerates and marls above the coast yielded a cluster of four or five large specimens of *Helix bateae* and a few *Clausilia bidens*. On the shore near St. Paul's Bay town are cliffs of loosely consolidated Quaternaries, with scraps of bird- and other bones, while to the north-east of this, along the south shore of the bay, are more massive and hardened red conglomerates, but apparently without bones or shells.

Benghiza Gap.

This locality near the south-east extremity of Malta was rendered famous by the researches of Leith Adams, who obtained many bones of *Elephas*, *Myoxus*, etc., from it. It consists of an old valley, now an indentation of the coast, some 600 feet long, at the top end and along the sides of which an old infilling of Quaternary beds reaching a thickness of about 30 feet is seen. The sea is breaking in again and washing out the old conglomerates, but the site is now unfortunately being used as a rubbish dump. Most of the part containing the bones found by Adams must have been washed away, as the only relic I found was a splinter of elephant tooth near the middle of the deposit at the top end. No land shells were seen. The surface of the Lower Coralline Limestone is seen to be reddened and blackened in one or two places beneath the conglomerate, which contains vast numbers of red, grey, and black limestone fragments. Heaps of large angular blocks occur at the base ; the middle part is a series of alternations of brown clay and layers of pebbles, and the top layer is a well calcreted red calcareous laminated clay with small stones.

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[1] Acts xxvii, 41.

Marsascirocco Bay.

On the north side of the bay, opposite Birzebbugia, a little north-west of Fort St. Lucian, a depression has been eroded in the Globigerina Limestone and the coast is occupied for some distance by Quaternary beds :—

1. Surface soil.

2. Grey marl up to 5 feet thick : this may be a later deposit lying partly in an eroded surface of the bed below.

3. Red clay with occasional black pebbles and calcareous concretions 7 feet thick. *Helix* cf. *variabilis*, etc.

4. Hard calcreted layer at the bottom of the valley, 8 inches thick.

5. Globigerina Limestone.

Sir A. Keith writes (*Neanderthal Man in Malta*, p. 270) concerning this locality : " Mr. C. Rizzo, an eminent Maltese geologist, had already formed the opinion that this harbour (Marsa Scirocco) represented what is left of a large freshwater lake." In reality the Quaternary deposits of this bay differ in no particular way from those of other localities and no trace of freshwater fossil mollusca has been found in Malta either by Dr. Baldacchino or myself.

St. Thomas Bay.

About 10 feet of a Quaternary deposit with blackened pebbles is exposed along the north-west shore of this bay. It is pink at the base for 2–3 feet, then yellowish for 4 feet, and is capped by a surface of hard calcreted material. The deposit looks a relatively late one, and yields *Helix* cf. *variabilis*, *H. schembrii*, etc.

Wied il Ghazel. Pl. II, fig. 1.

Near St. Margherita church at the side of a shallow tributary stream near a bridge, a small mass of Quaternary conglomerate remains perched on a sort of low pedestal of Globigerina Limestone left by the erosion of the stream, 10–12 feet above its present bed. There is a foot or two of calcareous concretionary marl at the base, and on top of this comes 6 feet of waterworn limestone pebbles, some of them black and red and well calcreted together. *Hippopotamus* remains: teeth, tusks, vertebrae, etc., are plentiful among the conglomerate, but apparently no land shells occur.

The Ghar Dalam Cave.

This cave is unique in Malta as regards size and richness of contents; it is a long natural gallery in the Lower Coralline Limestone, having its entrance on the north-east bank of the Wied Dalam, about 30 feet above the present bottom of the valley. It penetrates for 270 feet, after which it grades off into several narrow branches, and is said to be about 700 feet long. The main portion is 20–60 feet wide and 10–18 feet in height. If one crawls along to the narrow portions of the cave one perceives that it is a well-waterworn channel, the passage partly blocked by large waterworn fallen masses, but where it commences does not seem to be precisely known. Towards its opening also the cave is waterworn, and one can see how water, percolating down cracks, has dissolved the rock away. At the bottom there is a channel with undercut sides, the sides having here and there broken away and fallen on to parts of the bone breccia or other contents of the cave during the process of infilling. Outside the cave the higher slopes of the Wied Dalam are gentle and terraced, but the lower part below the cave entrance is gorge-like, flat-bottomed, and bounded by vertical, or in some parts, undercut sides. Dr. Baldacchino thinks a continuation of the cave exists at the same level on the opposite side of the valley, but the entrance of this other cave or fissure, which is full of red earth, is blocked by large fallen masses which would require to be blasted away. It seems probable, therefore, that the valley has been cut down to its present level after the formation of the cave.

The deposits in the cave are thickest near the entrance, and the accumulated mass slopes downwards and thins out towards the innermost parts of the cave, which are very wet and seem to have only a thin deposit of sticky clay on the floor.

A great deal of excavation has been done at different times in this cave and the more recent results are embodied in the Annual Reports of the Museum Department of Malta.

Contrary to a prevalent idea, the deposits have not been to any extent disturbed since their deposition. Generally speaking they are:

1. Historic layer. Dark reddish earth, 7–9 inches, with remains of animals and shells and potsherds of Punic to recent times.

2. Prehistoric layer, 12–15 inches. Small angular stones and pebbles of Coralline Limestone embedded in a darkish grey soil or clay which tends to break up into cuboid or dice-like fragments; bones of man and animals and many land shells, including the large, extinct *Helix melitensis* var. *despotti*. Prehistoric potsherds of megalithic type, flint, chert, and obsidian implements and sling stones made of Globigerina Limestone.

3. Very fine loose red earth up to 2 ft. 6 in. thick practically free from stones and with no pottery or other artefacts. A stalagmitic floor from ¼ to 1¼ in. thick almost completely separates this bed from the one above. Bones of *Vulpes*, *Arvicola*, etc.; land shells only in the upper half.

4. Angular stones and pebbles embedded in a dark red earth, the whole cemented by stalagmitic matter; 6 inches thick. One hippopotamus bone, otherwise the remains are entirely of deer, many of the specimens being rolled and highly mineralized.

5. Tough pale tenaceous clayey red earth, 2 feet thick. *Canis*, *Cervus*, *Hippopotamus*, birds, *Testudo* (small species). Layers 3, 4, and 5 are called the Red Earth layers.

6. Bone breccia. A large quantity of bones together with small pebbles embedded in a red clayey earth, the whole cemented with stalagmite. It is 9–15 inches thick. The remains are in utter disorder, bones rolled to pebbles are found side by side with specimens in a perfect state of preservation. This layer yields no bones of deer; two species of elephant are present, but apart from these the breccia was entirely composed of bones and teeth of a small hippopotamus.

7. Sterile layer. Pale plastic clay, very finely laminated, up to 6 feet thick, apparently devoid of any animal remains.

A recent excavation, October, 1936, which I examined, near the entrance of the cave showed about 10 feet of deposit:—

1. Red earth, rather thick, poor in bones but chiefly deer.

2. Bed of waterworn limestone pebbles confined to the west half of the cave, becoming replaced eastwards by red earth which passed in places underneath the pebble bed.

3. Layers of massed hippopotamus and elephant remains partly under fallen limestone blocks.

4. Sterile blue finely laminated clay.

No very distinct line of demarcation except a rather inconsistent bed of rolled limestone pebbles separates the masses of hippopotamus and less numerous elephant bones and teeth, the so-called "bone breccia", from the red cave earth above. In the cave earth deer and carnivora such as *Ursus*, *Canis*, etc., appear, and these bones are generally much less rolled, but some pieces of deer horn I found were rolled and highly mineralized. Dr. Baldacchino, however, recently found two complete elephant tusks high up in the red earth layer.

The limestone pebbles in the bone breccia are not at all reddened or blackened, but a few of the pebbles near the top of the red earth are slightly darkened, probably by infiltration.

It is misleading to compare Ghar Dalam with the Grotte du Prince at Mentone, or to suggest that the rolled bones at Ghar Dalam are a sea beach effect.[1] At the base of the Grotte du Prince there is a raised marine beach with *Strombus bubonius* and other shells, but the main bone beds in Ghar Dalam are probably much earlier than the Mentone cave deposits. There is no indication of marine action at Ghar Dalam either in the formation of the cave or the material filling it. The whole bone deposit between the sterile layer at the base and the prehistoric layer at the top gives an impression of unity, and looks like an early Quaternary deposit formed comparatively rapidly.

Reported Occurrence of Neanderthal Man in Ghar Dalam Cave.

Vaufrey has already denied that the discovery of "taurodont" human teeth in this cave prove the existence of Neanderthal man in Malta, but the question perhaps needs some further explanation. Sir A. Keith [2] illustrates the two taurodont teeth, in a sketch of the cave section, as occurring in the red earth layer, but some distance apart and at different levels; though he asserts that both teeth belong to the same individual. They were found 110 feet in from the entrance of the cave. Descriptions of the actual finding are conflicting. G. Despott [3] records that in the second layer of fine red silt, 1–1½ feet thick, the larger molar with conjoined roots was found with land shells, chiefly *Helix despotti*, and implements consisting of sling stones, a flint scraper, obsidian scrapers, a chert knife, and a piece of blackish flint. All these implements, as the illustration shows, are obviously of the Megalithic culture. The other tooth, a milk molar, is reported to have occurred in the layer below, 2 feet thick, which consisted of fine red earth in which were embedded some rounded stones and bones, teeth, and antlers of stag.

C. Rizzo [4] writes: "Last but not least, besides other human remains two human molars of a particular type, viz. a first upper molar and a milk molar, were brought to light in 1917, of which the first was found by the writer among a quantity of cervine teeth which the workmen had picked up and put in a box, while the other was found by Mr. Despott some days afterwards. The molar found by me presented, in my view, special features characteristic of Palaeolithic man, and I suggested to Mr. Despott that it should be forwarded to the British Museum for proper identification ".

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[1] Sir. A. Keith, *Neanderthal Man in Malta*, and H. Peake and H. J. Fleure, *Hunters and Artists*, 1927, p. 16.

[2] Sir A. Keith, "Neanderthal Man in Malta," *Journ. Roy. Anthrop. Institute*, liv, 1924, 251–274.

[3] "Excavations at Ghar Dalam, Malta, in the summer of 1917," *Royal Anthrop. Institute*, xlviii, 1918, p. 221.

[4] *Report on the Geology of the Maltese Islands*, Malta, Govt. Printing Office, 1932, p. 20.

I recently examined the two teeth in question with a lens. They are both in precisely the same condition, the deep fissures and cavities of the enamel show no trace of red earth ; at the base of the root of the larger tooth the " operculum " is in place, having never been detached, but is still joined by about a third of its circumference, the remainder being open. The pulp cavity appears quite empty of earth, but there are traces of a grey marly matrix on the sides of the roots. Dr. Baldacchino showed me other human teeth with ordinary divided roots from the Neolithic layer in another part of the cave, in the same condition of mineralization as the two taurodont teeth.

One at least of these teeth is definitely from the culture layer, and my conclusion is that they are teeth either of the Megalithic people or of the people who brought a Tardenoisian-like core of yellow flint which was found by T. Ashby in the upper layers of the cave and is now in the Ghar Dalam Museum. From various evidence I concluded that man may have reached Malta about 4000 B.C. and have occupied some of the caves, and commenced building Megalithic structures not long after that date. No trace of Palaeolithic implements has turned up in Malta.

Vaufrey says that in Sicily man did not appear till late in the Palaeolithic, and that the elephant beds there contain no trace of anything human.

The Megalithic Culture.

The antiquity of this culture in Malta has recently given rise to some discussion, and as some extinct forms of *Helix melitensis* occur in connection with it, the matter is of some importance regarding the Quaternary conditions. The late Italian archaeologist, L. M. Ugolini, made somewhat enthusiastic claims both as regards the antiquity and influence of this culture.[1] On the other hand, Professors J. L. Myres and V. Gordon Childe [2] refute Ugolini's theories and express the view that this Maltese culture is a late retardation and was in operation when most of Europe was in a bronze age. The reasons given are, among others, that Malta is an " isolated " island, comparable in a cultural aspect with " Northern Europe ", by which, presumably, Scandinavia is meant. In reality Gozo is about 50 miles from Sicily, only 4 or 5 miles more than Crete or Cyprus from the nearest mainland. Malta may have been nearer 5,000 years ago, when one takes into consideration the late submergence and cliff erosion. Crete and Cyprus have an authentic Neolithic culture which these archaeologists apparently deny to Malta.

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[1] *Malta, Origini della Civilta Mediterranea*, 1934.

[2] Letters to *The Times*, 29th Oct., 1936.

Various evidence from stratigraphy in the Ghar Dalam and other caves and on Megalithic sites show that the Neolithic culture is separated by a very marked hiatus from the historical culture layer of Phoenician times. The late Palaeolithic-reminiscent character of most of the implements, the local derivation of the material, Lipari obsidian, grindstones of Etna lava, similarity of pottery with that of Neolithic Crete, etc., lead one to the conclusion that the Megalithic culture is an early one dating back to before 2000 B.C.

Sir T. Zammit's careful excavations showed that some 2·35 metres of debris covered the temple of Tarxien and that burials of a Copper age occurred 90 cm. above the floor of the temple. The slight relief and rocky nature of the surrounding country gives little opportunity for any great amount of material to be washed down, while the thinly populated condition of Malta before quite modern times would prevent much artificial accumulation. There appears to be no positive evidence that this culture is a late retardation, and doubtless Zammit's and Ugolini's views are the more correct.

A Cave near Musta Fort.

The Victoria line of fortifications, looking like a miniature "Wall of China", runs across Malta practically along the Great Fault and descends a rocky gorge leading to the Wied el Ghazel, near Musta Fort. Here, on the west side of the gorge, about 70–80 feet above the bottom of the valley, a small cave opens out on the steep rocky slope. It has evidently been larger and has been cut back by solution. The contents have mostly been dug out, probably when the lines were constructed, but a quantity of the one-time calcreted grey infilling still adheres to the slope outside the cave. This material is about 10 feet thick, and has many hippopotamus teeth and bones, some of them much rolled, also deer teeth and rounded waterworn pebbles of limestone, not reddened or blackened. These, presumably, must have been washed in when the cave was not much above the bottom of the valley, which has therefore been much deepened since the cave deposits were formed. The deep gorge has evidently been cut down by the stream during a rise of the upthrow side of the fault scarp, indicating that the Grand Fault of Malta has moved in Quaternary times.

The Island of Gozo.

Gozo differs from Malta in having much more of the blue clay and greensand, which has been largely denuded off the main island, and is in consequence more fertile. Remnants of Upper Coralline Limestone capping the softer formations form picturesque small table or pyramid-like hills. On Gozo the Quaternary beds, easily recognizable from a distance by their red and pink colour, occur as isolated patches clinging to valley sides or to cliffs near the sea, and consist of masses of conglomerates and marls generally with strongly calcreted cappings. They are much eroded and tend to break and slip away owing to the beds beneath being soft, and the modern rivulet courses of the island show that a new system of denudation has commenced independent of the flood waters or whatever it was that formed the Quaternary conglomerates.

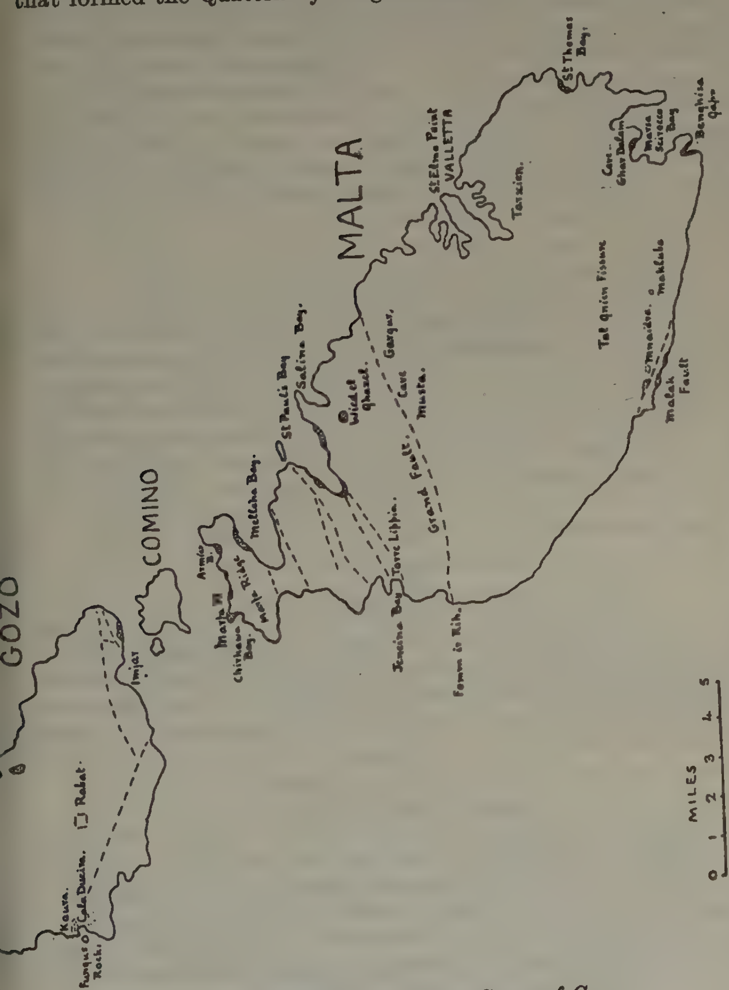

FIG. 1.—Locality Sketch Map of the Maltese Islands. Interrupted lines show approximately the directions of the chief Fault dislocations. Dotted patches indicate some of the Quaternary conglomerates.

Cala Dueira Area, West Coast of Gozo.

This locality was described by J. H. Cooke,[1] who lists all the land shells from it as living forms. The small patches of Quaternaries on his sketch map, south-east of the Fungus Rock on the valley sides yielded only scraps of bird- and other bones and some land shells.

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[1] GEOL. MAG., XXXVIII, 1891, 348.

Half a mile north of Cala Dueira, near Ras id Dueira and Kaura there is a circular lagoon into which the sea enters through a hole in the cliff, the fault makes another semi-circular deviation, and perched up against the sloping fault face there is a patch of Quaternaries up to 30 feet thick. They rest on the greensand and blue clay, which are here faulted down against the Lower Coralline Limestone, and both the clay and the Quaternaries are much weathered and are slipping away. The Quaternary beds are marly below and more conglomeratic above, and are full of red and black pebbles. Only fragments and scraps of bone were found, but land shells are plentiful; a cluster of *Helix bateae*, the large *aspersa*-like form, were found at one spot.

Wied ta Marsalform, near the North Coast of Gozo.

On the east side of this valley, 2 miles north-east of Rabat, the capital of Gozo, a considerable thickness of red Quaternary marl and conglomerate is seen resting against the valley side, about 200 feet above sea level. It is breaking away and slipping down in large masses; is full of red and black stones; and contains crushed land shells, among which is apparently *Helix bateae*. A good view of this bed and its relation and contrast to the present drainage of the island can be obtained from the elevated walls and battlements of Rabat or Victoria Town, the capital.

South-east Coast of Gozo.

One and a half miles east of the landing place at Imjar, 30 or 40 feet of coarse red conglomerate, overlain by marl and calcrete, is banked up against the sloping cliff face a little above sea level. There are many red and black scorched pebbles and stones, but neither land shells nor bones were seen.

FOSSIL LAND SHELLS.

In 1933 Dr. Baldacchino showed me some fossil land shells he had collected at Marfa; these appeared to me to differ appreciably from the living forms, an opinion which he also seemed to share. Most of the earlier writers on Malta record the fossil or semi-fossil land shells as identical with living species, but C. Rizzo (p. 17) writes that at Melleha, Marfa, etc., he collected " several shells of various species of *Helix* and other land shells all locally extinct ". I paid special attention to collecting these mollusca, and their examination shows that while a certain number are extinct others are more closely allied to living forms; a proportion are still living on Malta, while a few of the present-day Maltese living forms are absent from the Quaternary beds. Land shells are not found in all the deposits, and generally where bones occur in plenty land shells are not found, and where land shells occur there are only scraps of bone or none at all. Sometimes they occur in little clusters, or else sporadically distributed. The Ghar Dalam cave yields no land shells except in the highest layers of the red earth, and the Neolithic layer. The Tal Gnein fissure, an old deposit with bones of giant tortoise, yielded no land shells.

There can be little doubt therefore that the land shell fauna is of later date than the main mass of the bone deposits, and probably lived when the climate was recovering from the arid period that caused the scorching of pebbles and rock surfaces.

The following species, common in Southern France, Algeria, etc., do not occur in Malta: *Helix melanostoma* Drap.; the edible *H. pomatia* Linn.; and the large carnivorous *Zonites algirus* Linn. The following are peculiar to Malta but not yet found in the Quaternary beds: *Helix* (*Jacosta*) *spratti* Pfr., confined to Gozo; the remarkable sculptured scalariform *Clausilia scalaris* Pfr.; and the sculptured barrel-shaped *Clausilia mamotica* Gul., confined to Gozo.

Common on Malta and elsewhere, but not seen in the Quaternary deposits, is *Helix* (*Leucochroa*) *candidissima* Drap., and *H.* (*Euparypha*) *pisana* Müll.

Helix (*Cryptomphalus*) *bateae* sp. nov. Pl. I, figs. 1, 2, and 3.

Shell of 4–5 whorls increasing rather rapidly in size, spire rather small and low relatively to the body whorl, which is large and inflated and drawn out laterally, suture not much sunken, the outer lip generally not very spreading nor much reflected, but variable in this respect. Aperture circular to ovate, the inner lip with a rather spreading callosity; growth lines fine but tending to be obscured by a finely vermiculate surface. Colour markings are mottled like those on *Helix aspersa*.

Dimensions and Locality.—Variable in size; large examples from St. Paul's Bay and Cala Dueira are 37 mm. long and 29 mm. high, the body whorl being 23 mm. high; small but apparently adult specimens from Malak gap are 23 mm. long and 18 mm. high.

Affinities.—Some individuals of this species come very near the common *H. aspersa* Müll., but the spire in the fossil is constantly smaller in relation to the body whorl, the sutures are less sunken, and the aperture generally more turned downwards; the outer lip in the fossil is also generally less spreading and less everted, and the shell surface more sharply vermiculated.

It approaches in some features the living Sicilian *H. mazzulli* Jan., in the shallowness of the suture and the inflation of the body whorl relatively to the spire and the slight spread or eversion of the

Fossil Land Shells of Malta.	Marfa Point.	Armier Bay.	St. Paul's Bay.	Malak. Top of cliff.	Malak. Bottom of cliff.	St. Thomas Bay.	Marsascirocco Bay.	Valletta shore (fissures.)	Cala Dueira, Gozo.	Neolithic	Living.	Remarks.
Helix (*Cryptomphalus*) *bateae* sp. nov.			+	+					+			Near the living *H. aspersa*.
,, (*Otala*) *protovermiculata* sp. nov.	+	+	+		+		+	+	+			Near the living *H. vermiculata*.
,, (*Helicella*) *baldacchini* sp. nov.	+	+										
,, (*Iberus* ?) *rizzoi* sp. nov.	+	+					+					
,, (*Cochlicella* ?) *zammiti* sp. nov.	+	+		+			+					
,, (*Cernuella*) aff. *durieuri* Moq-Tand.		+										Near living Algerian form.
,, (*Turricula*) *calcarata* Benoit		+									+	Living, Malta only.
,, (*Trochula*) *schembrii* Pfr. var.				+	+	+	+				+	Living, Malta only.
,, (*Heliomanes*) *maritima* Drap.						+	+					Living, Italy, Algeria, etc.
,, (*Heliomanes*) *variabilis* Drap. var.						+	+					Living, Algeria, Malta (?).
,, (*Heliomanes*) *caruanae* Kobelt		?					+					Living, Malta only.
,, (*Xeroclivia*) spp.	+											
,, (*Iberus*) *melitensis* var. *despotti* C.-G.										+		In Ghar Dalam Cave.
,, (*Iberus*) *melitensis* var. *megalithica* nov.										+		On Megalithic site.
,, (*Euparypha*) *pisana* Müll.							?				+	Living, Mediterranean, etc.
,, (*Helicogena*) *aperta* Born.											+	Fossil, Malta, in B.M. Coll.
Mastus pupa Brug.	+	+									+	Living, Mediterranean.
Rumina decollata Linn.	+	+		+	+		+		+	+	+	Living, Mediterranean.
Clausilia (*Papillifera*) *bidens* Linn.		+		+				+		+	+	Living Mediterranean.
Cyclostoma cf. *sulcatum* Drap., var.										+		Near the living *C. melitensis*.

lip. *H. mazzulli*, however, has a more variable and generally higher spire and stronger growth lines, but has a sharply vermiculate surface rather like that of *H. bateae*.

H. bateae seems to be a form intermediate between *H. aspersa* and *H. mazzuli* but nearer to *H. aspersa*.

In the Cooke collection in the British Museum, Natural History, is a shell (G. 28130) from the *Hippopotamus* bed, red breccia, Hamrun, labelled " *H. aspersa* ", but with very much the appearance of some examples of *H. mazzulli*, but it is badly preserved. The Hamrun ridge, west of Valletta, from which Cooke collected, is now entirely built over.

In the British Museum collection, in post-pliocene breccias of Gibraltar, a large *aspersa*-like *Helix*, very badly preserved, occurring with *Rumina decollata*, appears to resemble this Maltese fossil. I propose to name the species after Miss D. M. Bate, who brought some specimens of it back from her visit to Malta in 1934.

Helix (*Helicogena*) *aperta* Born.

In the Leith Adams collection in the British Museum is a poorly preserved specimen of this species labelled " Caverns, Malta, associated with *Myoxus melitensis* ". This species is common living on Malta, S. France, Algeria, etc., but I have not seen it in the Quaternary beds.

Helix (*Otala*) *protovermiculata* sp. nov. Pl. I, figs. 4, 5, 6, and 7.

Description.—Shell of five whorls which increase rather rapidly in size, the last whorl being well inflated. The spire tends to be rather flattened or depressed but is more elevated in some specimens, sutures well marked but not deep ; towards the aperture the shell is decidedly bent downwards, the outer lip rather thickened and moderately turned backwards or everted. The shell underneath and adjoining the aperture is gently rounded and the umbilical region rather hollowed or flattened. Colour markings are often well preserved, and consist of more or less mottled bands of varying thickness. Size variable, a large specimen is 32 mm. in diameter and 19 mm. in height.

Locality.—Marfa Point, Armier Bay, in Malta ; Cala Dueira, in Gozo, etc.

Affinities.—This fossil *Helix* is closely related to *H.* (*Otala*) *vermiculata* Müll., common living in N. Africa, S. France, Malta, etc., and may be ancestral to it. The living form is very variable as regards ornamentation, height of spire, degree of inflation of the body whorl, and extension and eversion of the outer lip. It sometimes attains a larger size than the fossil, often has a more elevated spire, the outer lip more spread, and the sutures deeper and wider. The living shell also has the surface below and adjoining the aperture more inflated and rounded than in the fossil and the aperture generally less sharply turned downwards; the whorls also increase more rapidly in size and the body whorl is less inflated relatively to the earlier whorls than in the fossil.

Some of the fossil specimens, for instance at Cala Dueira, or in the presumably later Quaternary beds at Marsascirocco Bay, can scarcely be distinguished from some examples of *H. vermiculata*, but in the case of specimens from Marfa, Armier, etc., the fossil is quite different from its living analogue.

The Upper Miocene *Helix turonensis* Desh., from the Faluns of Touraine, France, resembles in some ways the Maltese fossil, but is a smaller and more solid shell.

Helix (*Helicella*) *baldacchini* sp. nov. Pl. I, figs. 8, 9, 10, 11, and 12.

Description.—Shell of 5 whorls, moderate in size, dull whitish in colour; some specimens have traces of mottled colour markings; the apex is often yellowish in colour. The shell is rather thick and solid, the spire varying in height, in some examples it is depressed, in others rather elevated; the aperture rounded to broadly semilunular in outline; in some there is a thin callosity on the inner lip. The umbilicus is small and narrow but deep, the last whorl bounding the umbilicus is rounded below. The whorls of the shell are inflated and well rounded, the suture deep, well marked, and distinctly incised, the slopes bounding it rounded. Growth lines are closely set, coarse, solid, and irregular, with frequent interruptions where the shell has been broken; they pass gently backwards from the suture and slightly forwards again below on reaching the umbilicus. The growth lines often fuse into one another and have a waxy look under a lens.

Dimensions.—Diameter up to 15 mm., height up to 12 mm., but rather variable, most specimens being rather smaller than this.

Locality.—Marfa Point, Armier Bay, etc., on the Marfa Peninsula.

Affinities.—It is not like any Mediterranean form I know. The living *Helicella* (*Cernuella*) *durieuri* Moq.-Tand., from Algeria, is smaller and has a much more elevated spire, the aperture is rounder, the shell thinner and less solid, and the growth lines more regular, though the suture is similarly sunken. *Helix* (*Heliomanes*) *turbinata* Jan., from Cyprus, has six whorls, is smaller, and has a more elevated spire, much less sunken sutures, narrower umbilicus, and more circular aperture, thinner shell, and thinner callosity on the inner lip.

The fossil seems to come nearest to the living *Helicella* (*Heliomanes*) *accompsia* Bourgt, from Algeria, but *H. accompsia* is considerably larger and has seven whorls, generally a more elevated spire, the sutures less sunken, the whorls less rounded below and a broader and deeper umbilicus, a less rounded aperture, and finer and more regular growth lines. This fossil *Helix* appears to be a new species and has the relatively solid shell, waxy surface, and strong growth lines suggestive of a desert or arid climate form. I propose to name it after Dr. J. G. Baldacchino, Curator of the Natural History Department of the Malta Museum.

Helix (*Cochlicella* ?) *zammiti* sp. nov. Pl. I, figs. 14, 15, 16, 17.

Description.—Shell small, thick, compact, solid, of six whorls which increase gradually in size, spire elevated but varying somewhat in this respect. The first two whorls are smooth, later whorls carry strong, rather irregular growth lines, which tend to merge into one another and pass backwards to the periphery and then slightly forwards to the umbilicus. The suture is deep and well incised and the penultimate whorl tends rather to overhang the suture. The periphery of the last two whorls has a more or less distinct broad, elevated ridge, on crossing which the growth lines become stronger. This ridge on the penultimate whorl occurs just above the suture; otherwise the whorls are well rounded and inflated, and the base of the shell around the umbilicus is inflated and rounded. The umbilicus is narrow and rather deep, the aperture nearly circular, the callus deposit on the inner lip very thin. Growth lines tend to erode and weather away, and traces of apparently mottled colour markings occur on some specimens.

Dimensions.—Height 6 mm., diameter 6·5 mm.; a larger specimen is 6·5 mm. high and 9 mm. in diameter.

Locality.—Marfa Ridge, Marsascirocco Bay, etc.

Affinities.—This small compact and solid shell is suggestive of an arid or desert form in its dull colour and waxy appearance; and also recalls in general manner some of the small solid Helices of Madeira. *Helix* (*Trochula*) *schembrii* Scacchi, of Malta, a common living species, carries a similar but stronger peripheral ridge, but is a more conical trochoid shell, more flattened below, with a rather wider umbilicus, an oval aperture, shallower sutures, and a more angular body whorl.

This appears to be a new species and I propose to name it after Mr. Charles Zammit, son of the late Sir T. Zammit.

Helix (*Trochula*) *schembrii* Pfr. var.

Fossil Helices resembling this form are common at St. Thomas and Marsascirocco Bays and rare in the conglomerate at Malak. The living shell is often larger and thinner, with the peripheral ridge more prominent and the umbilicus wider and deeper. The fossils sometimes take on characters approaching the more compact and solid shell *H. zammiti* sp. nov.

Helix (*Turricula*) *calcarata* Ben.

One specimen of this ornamented *Helix* occurred in the red clay near Marfa Point. It lives at present on Malta, but its still flatter and more strongly keeled relative *H. spratti* Pfr. is confined to Gozo, but has not been found fossil.

Helix (*Iberus* ?) *rizzoi* sp. nov. Pl. I, figs. 20 and 21.

Description.—Shell rather thin, of five whorls, increasing gradually in size, sutures well marked and adjacent whorls well rounded, spire rather elevated. Body whorl well inflated, diminishing in size near the aperture, which is perceptibly contracted and turned downwards. Aperture subcircular, outer lip thin, spreading, and moderately everted; on the underside the shell is well rounded, but rather hollowed out or saucer-like at the umbilicus; there is a thin hollowed out spreading callosity of the lower lip. Surface glossy, faintly and broadly vermiculate, with fine growth lines seen especially below the sutures.

Dimensions.—Longer diameter, 25 mm., height 16 mm., height of body whorl 12 mm.

Locality.—Marfa Peninsula, Marsascirocco Bay, etc.

Affinities.—It has no close resemblance to any *Helix* I know. The lower lip, with its tendency to a tooth-like spreading enlargement, suggests that of *H.* (*Iberus*) *melitensis* Fér. The contracted aperture recalls that of *H.* (*Murella*) *sicana* Fér., a Sicilian shell, but the latter has a higher spire and a still more contracted aperture.

I propose to name it after Mr. C. Rizzo, Director of the Malta Museum.

Helix (*Iberus*) *melitensis* var. *despotti* Caruana Gatto. Pl. I, fig. 29.

This variety was named but not described in a report on "Excavations conducted at Ghar Dalam, Malta, in July, 1916", by Mr. G. Despott, to the British Association, Section H, Newcastle, 1916. A typical specimen from the cave is 27 mm. in diameter and 17 mm. high, the whorls well rounded, spire not elevated, sutures well marked but not deep, outer lip not prominent nor much everted, lower lip feebly toothed or spread below. Mottled colour markings, generally in two bands on the upper surface of the shell, are often well shown.

Locality.—Neolithic and upper part of the red earth layer in the Ghar Dalam cave. They may have crept down into the red earth when alive. A broken specimen, apparently of this variety, occurred at Armier Bay.

Affinities.—They are very like mottled specimens of the living *H. melitensis*, but are considerably larger, an average specimen of the living form being 19 mm. in diameter and 13 mm. high.

Helix (*Iberus*) *melitensis* var. *megalithica* nov. Pl. I, figs. 27 and 28.

Diameter 30 mm., height 20 mm., shell of five whorls, spire moderately elevated, rounded, sutures well marked, but not deep, body whorl rather inflated, outer lip strong and rather everted. Surface glossy or waxy looking with little trace of colour markings, the lower part of the outer lip has a broad but not well defined, hollowed-out swelling.

Locality.—This variety was collected in the Neolithic ashy culture layer with pottery, implements, etc., of a small ruined Megalithic structure half fallen over the cliff edge at Torre Lippia, Jeneina Bay, West Malta. It is much larger than the living *H. melitensis* and is so large that till it was cleaned I mistook it for *H. variabilis.* It also seems to be more constant in character and to vary less in height of spire than the living form; the latter also has a more defined tooth on the lower outer lip.

Helix (*Cernuella*) sp. Pl. I, fig. 13.

Shell of six whorls increasing gradually, spire elevated, sutures well sunken, whorls rounded on the sides and below, with a deep but not wide umbilicus, aperture subcircular, growth lines very fine, surface dull and white. Height 10 mm., diameter 9·5 mm.

Locality.—Armier Bay. This shell, of which there is only one specimen, resembles the living Algerian *Helicella* (*Cernuella*) *durieuri* Moq.-Tand., but has the spire more elevated, the protoconch smaller, a deeper and wider umbilicus, and seems a stronger and thicker shell.

Helix (*Heliomanes*) *variabilis* Drap. var. Pl. I, figs. 18 and 19.

Fossil Helices resembling this species but having perhaps the body whorl less inflated and the umbilicus narrower, are common at St. Thomas and Marsascirocco Bays in the later and softer beds. Other banded Helices in the same beds resemble *Helix* (*Heliomanes*) *maritima* Drap. Others with a gently arched spire and shallow sutures are more like *H.* (*Cernuella*) *caruanae* Kobelt, a species confined to Malta at the present day. It is doubtful whether *H. variabilis* lives on Malta at the present time; *H. maritima* is an Italian and Algerian species.

Helix (*Euparypha*) *pisana* Müll.

This universal circum-Mediterranean species which has an outpost of finely coloured specimens on the Castle Rock at Tenby, S. Wales, has not been found in the Quaternaries of Malta, except for one specimen from Marsascirocco Bay, which may, however, be from the surface soil.

Xeroclivia spp. Pl. I, figs. 22, 23, 24, 25, and 26.

Small conical, turreted, or pagoda-like Helices occur in the red conglomerate at Marfa Point, etc., often in clusters. They are evidently related to such living forms as *X. caroni* Desh., of Sicily; *X. liebetreui* Alb., of *Cyprus*; or *X.* (*Trochoidea*) *terrestris* Penn., a common S. France and Algerian species. It is often difficult to see if the specimens are complete, and as they seem to merge into one another, it seems useless to give new species names to these fossils, but their characters are as follows: *Xeroclivia* sp. Height 5 mm., diameter 3·5 mm., shell of seven whorls, the protoconch yellow in colour, the rest of the shell white. The first two whorls are scarcely keeled, the last three acutely keeled, pagoda-like, concave above the keel, which is prominent and thickened; surface below gently rounded with a small shallow umbilicus. Growth lines finely marked, not foliaceous.

Xeroclivia sp. Height 7·5 mm., diameter 5·5 mm., trochoid, of about eight whorls, sutures slight, the body whorl angulated, gently rounded below, growth lines fine not foliaceous.

Mastus pupa Brug. Pl. I, fig. 30.

Specimens apparently specifically identical, but with rather thicker shells and stronger growth lines than the living Maltese form, occur in the conglomerate and hardened dune rock west of the landing stage at Marfa.

Rumina decollata Linn.

Shells seemingly identical with the common living Mediterranean form are found in the red conglomerate at Marfa Point, and at Cala Dueira, Gozo, etc.

Cyclostoma cf. *sulcatum* Drap. var.

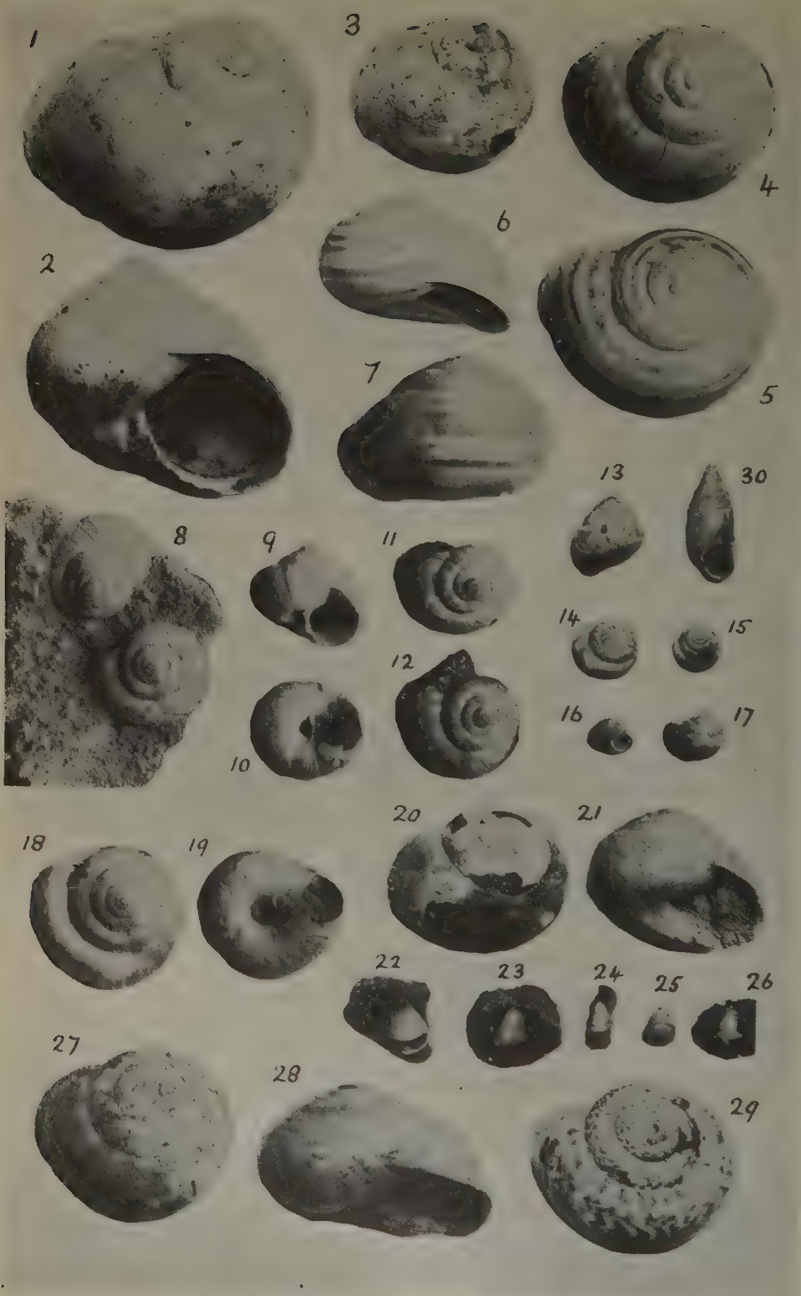
Shell 12·5 mm. high and 9 mm. wide; the body whorl carries fifteen or sixteen sharp ribs, separated by shallow interspaces, the aperture is almost detached from the body whorl.

The only living operculate on Malta is *C. melitensis* Sow., but the fossil is rather more like the Sicilian *C. sulcatum* Drap. In *C. melitensis* the ribs are weak and the aperture is attached to the whorl; in the fossil, however, it is less completely detached than in *C. sulcatum* and the fossil is smaller and more acutely ribbed than either of these living species. The umbilicus of the fossil more resembles that of *C. melitensis* and is less pronounced than in *C. sulcatum*.

Locality.—Cala Dueira, Gozo.

SUMMARY AND SUGGESTED CORRELATION.

1. There is no Eocene and no Pliocene in Malta; during the Pliocene the area of which the Maltese Islands are now a fragment became a land surface.
2. The Ghar Dalam and other caves were eroded during an early pluvial period. Pre-Chellean ?
3. The earliest bone deposits seem to be the dense accumulations of elephant, hippopotamus, and other remains in the caves and some of the fissures. Chellean or Kamasian pluvial of East Africa ?
4. An arid period intervened during which rock surfaces and limestone pebbles and debris were scorched and altered to a red or black colour. Pebbles in the caves are not reddened or blackened. Mindel-Riss interglacial ?



Fossil Land Shells from Malta.

5. A pluvial period followed; the Quaternary conglomerates and marls look like the result of cloudbursts acting on reddened desert material. These deposits often contain land shells distributed in a pocket-like manner. Some of these forms are extinct but allied to living species; a few have an aspect suggestive of arid conditions. Post-Riss pluvial ?

6. The later drainage and erosion has left the Quaternary surface deposits in the form of remnants generally attached to valley sides or cliffs near the sea.

7. Faulting has continued during Quaternary times. The uprise edge of the Great Fault has been cut down by streams forming deep gorges as it rose. At Malak, Quaternary conglomerates are involved along the fault planes. Mindel-Riss period of Rift faulting in East Africa ?

8. Malta has not suffered a vertical depression but more a tilting process. The high cliffs of the west coast seem to have risen as the down faulting off the coast took place and left as a remnant the islet of Filfla, 3 miles south-west of Malta. On the south-east coast the harbours are evidently partly drowned valleys of sub-aerial erosion. Consolidated dune rock around the Marfa Peninsula indicates that the north end of Malta was near the sea in some part of Quaternary times.

9. No Palaeolithic implements have been found in Malta and the search for them does not look promising. The Neanderthal-like teeth from the Ghar Dalam cave occurred in a superficial layer and probably belonged to the Mesolithic or Megalithic people.

EXPLANATION OF PLATES I AND II.

Plate I.

Nos. 1, 2, and 6 are natural size, the rest are enlarged about five-sixths.

Fig.

1.—*Helix* (*Cryptomphalus*) *bateae* sp. nov., north side of St. Paul's Bay.
2.—Ditto, sp. nov., Cala Dueira, Gozo.
3.—Ditto, smaller specimen, resembling *H. mazzulli*, Malak, top of the cliff.
4.—*Helix* (*Otala*) *protovermiculata* sp. nov., Armier Bay.
5.—Ditto, sp. nov., Cala Dueira, Gozo.
6.—Ditto, sp. nov., same locality, another specimen.
7.—Ditto, Armier Bay.
8.—*Helix* (*Helicella*) *baldacchini* sp. nov., Marfa Point, embedded in consolidated dune rock of aeolian origin.
9, 10, 11, 12.—Ditto, same locality, other specimens.
13.—*Helix* (*Cernuella*) sp., Armier Bay.
14, 15, 16, 17.—*Helix* (*Cochlicella*) *zammiti* sp. nov., Marfa Point and Armier Bay.
18, 19.—*Helix* (*Heliomanes*) *variabilis* Drap. var., St. Thomas Bay.
20, 21.—*Helix* (*Iberus*) *rizzoi* sp. nov., Armier Bay. Two specimens.
22, 23, 24, 25, 26.—*Xeroclivia* spp., Marfa Point, from the matrix of the red conglomerates; specimens varying in size and shape.
27, 28.—*Helix* (*Iberus*) *melitensis* var. *megalithica* nov. Two specimens from culture layer of ruined temple, Torre Lippia.
29.—Ditto, var. *despotti* Caruana Gatto, Red earth, Ghar Dalam Cave.
30.—*Mastus pupa* Brug., Marfa, west of the landing stage.

PLATE II.

Views on Malta.

FIG.

1.—Wied el Ghazel, between Musta and St. Paul's Bay. At the base is Globigerina Limestone G, overlain by Quaternary gravels Q, which are full of *Hippopotamus* remains. Modern stream erosion has left this isolated mass of rock and gravel.

2.—View of the Malak fault, looking north-westwards from the shore below Torre Hamria. The sloping fault plane has patches of crushed Quaternary conglomerates on it, and these occur also capping the semi-detached mass on the left. On top of the cliff in the middle distance is the neolithic Mnaidra Temple, and near this Quaternary beds occur, as well as on the slopes along the sea coast at the foot of the fault.

3.—Marfa Point, the north-west promontory of Malta, the high cliffs of the west side of Gozo in the distance. A, consolidated sand dune rock with fragments of marine shells and numerous *Helix baldacchini.* B, red conglomerate with scorched red and black pebbles, land shells among the matrix, resting on a surface, C, of Upper Coralline Limestone. The latter is smoothened by water action, slopes gently to the north-east, and shows traces of arid scorching.

The Rate of Sedimentation on Salt Marshes on Scolt Head Island, Norfolk.

By J. A. STEERS.

A BRIEF note on this subject was published in the GEOLOGICAL MAGAZINE, Vol. LXXII, October, 1935. In September of that year certain more detailed experiments were prepared, whose object was to afford a means of measuring the rate of accretion of tidal silt on different types of marsh in various parts of the island complex. Reference to Text-fig. 1 will show that five lines were prepared. In each case patches of fine and distinctive light brown Lower Greensand were spread over the marsh at measured intervals. Sometimes the patches, each about 2–3 feet in diameter, were put down at regular distances, but, on account of the number of small creeks and salt pans intersected by any straight line across a marsh, it was usually more convenient to make the intervals between patches irregular. The sand was spread as a fine layer in and on the vegetation, and after it had been covered by one or two big tides, it settled down easily on the true marsh surface under the plant covering. It was then only a matter of time before it was covered by tidal silt. The sand was put down in September, 1935, and the measurements of accretion were made at the end of June, 1937.

Before describing and commenting on the results, a brief summary of the island's structure is necessary.[1] Scolt Head Island is a form of off-shore bar which has grown from east to west, and has thrown out an excellent series of recurved ridges (laterals) on its landward

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[1] *Scolt Head Island*, ed. J. A. Steers, Heffer, 1934.

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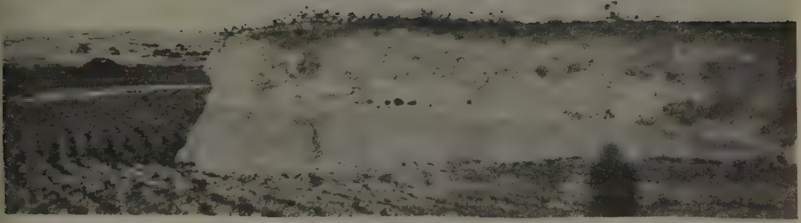

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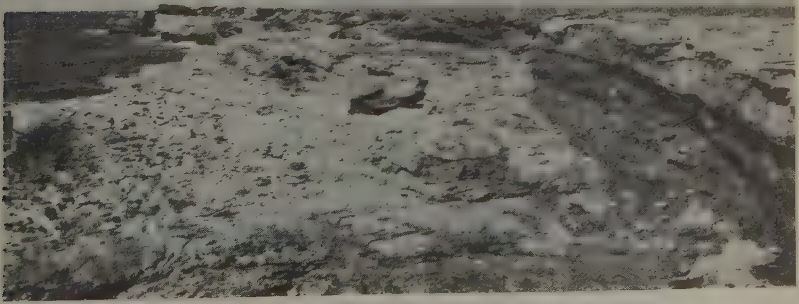
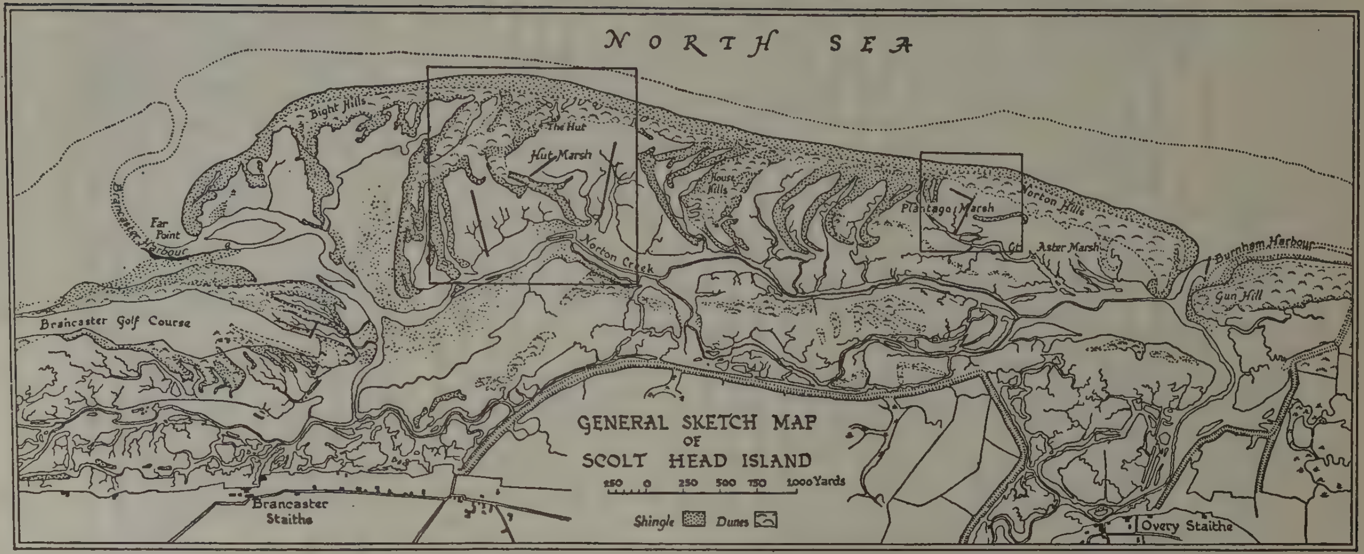


Views on Malta.

[To face p. 26.



Text-fig. 1.—The general positions of all lines are shown. The squares indicate the positions of Text-figs. 2 and 3. The line on Golf Links Marsh is shown about $\frac{3}{8}$ inch east of the name "Brancaster Golf Course".

side. These enclose areas of salt marsh, which, with the exception of the easternmost marsh, show an increasing age gradation from the bare sand-flats at the far west, to high marsh in the east. The island is separated from the mainland by Norton Creek, a wide channel at high water, but dry in much of its course at low water. It is by means of this channel, and the numerous marsh creeks running into it, that the tidal silt is carried to the marshes. South-west of the island lies Brancaster Golf Course, which consists of a series of shingle ridges and sand dunes. The newer ridges are outside (i.e., north of) the Golf Course, but all have grown eastwards in opposition to the direction of growth of the island. A line of sand patches was laid down at right angles to the major axis of one of the newer marshes of this series.

It will be appreciated that as the marshes enclosed within laterals are not all at the same height, and also that as in general there is a very slight slope, with occasional interruptions, on any marsh towards Norton Creek, the number of hours during which each marsh is submerged in any lunar month varies a good deal. This in its turn implies that those marshes which are most frequently covered give the higher rates of sedimentation. This is seen very well if, e.g., the Missel Marsh line is compared with that on Upper Hut Marsh. Another significant point may also be noticed. As stated above, the rising tide comes up Norton Creek and then fills the major and minor creeks. When these are full it spills over the whole upper surface of the marshes. A characteristic feature of the Norfolk marshes, especially the older members of any series, is that the creeks are lined with *Obione portulacoides*. This plant, of bushy habit, traps a good deal of silt, and acts as a filter for the water spreading from the creek on to the marsh. For this reason, amongst others, the rate of sedimentation is often rather higher near the creeks lined with *Obione*, and consequently the levels of marshes near creek banks are often measurably higher than elsewhere. It is natural to expect rather greater sedimentation near any creek, and the figures generally bring out this point, but the occurrence of *Obione* on the older marshes and its absence from the newer is a striking feature.

Experience has shown that this method of measuring accretion cannot easily be applied to all types of marshes. It would be of interest to have measurements for some of the new marshes, but it has been found that unless there is already a fairly close turf of vegetation, the sand is washed away, or so dispersed as to be unnoticeable in sample bores. Even in a closely covered *Salicornia* marsh the method is difficult to apply. At Scolt this plant colonizes bare sand or thinly mud-covered areas, and in late summer may form a dense carpet. But in winter all that is left are the stringy internal stems of the plant, and the flowing and ebbing tide can easily wash away a layer of sand from among them. The method has given best results in what may loosely be called " middle-high " marshes, where there is already a considerable accretion of mud, and where the plant covering is thick.

Before analysing the various lines, a word may be said about the general nature of the marshes selected for the experiments.

(*a*) *Hut Marsh.*

This is an extensive marsh drained by two major creeks and a large number of smaller ones. The long line labelled "Lower Hut Marsh" was put down across the marsh roughly at right angles to Norton Creek and between the two major marsh creeks (see Text-fig. 2). This part of the marsh is flooded by most ordinary spring tides, but is left bare during small range neap tides. It is seldom covered for more than about 1½ or 2 hours at any one tide, but occasionally the wind, if in the right direction, holds the water up for a slightly longer time. All minor creek banks along this line are fringed with *Obione*, and the whole line, apart from the *Obione* which excludes all other vegetation, consists of such plants as *Aster tripolium*, *Spergularia media*, *Salicornia* spp., *Suaeda maritima*, *Limonium* (*Statice*) *vulgare*, occasional patches of *Triglochin maritimum* and *Glyceria maritima*, and nearly everywhere a mat of the unrooted algae, *Pelvetia canaliculata* and *Bostrychia scorpioides*.

The upper part (i.e. western part for our present purpose) of this marsh is higher and is usually only covered during comparatively high spring tides, and then for but a short time, except very near the major creek. As shown below, the sedimentation rates are here very low, and in one case no record was available. This is probably because the sand put down on the parts farthest from the creek was blown away. It should also be remarked that much sand is blown on to this part of the marsh from the neighbouring dunes. The measurements obtained from this line, however, are consistent, and agree with the observed fact that this part of the marsh is much less often submerged.

(*b*) *Missel Marsh.*

The line put down here was near to, but not coincident with, that described in 1935. The lower part of this marsh is covered by a close turf consisting mainly of *Aster tripolium*, *Salicornia* spp., *Suaeda maritima* var. *flexilis*, *Spergularia media*, and occasional plants of *Limonium humile*, and *Triglochin maritimum*. There is again a dense covering of *Pelvetia canaliculata forma libera* and *Bostrychia scorpioides*. The upper part of the marsh is relatively bare, and is gradually being colonized by *Salicornia* spp. and other plants. The line of sand did not cover this upper part, as the former experiment showed that the sand was either washed away by the tidal waters or blown away by the wind. There are numerous creeks and pans of all sizes on the lower part of this marsh, and the line crosses one of the major creeks.

(*c*) *The Golf Links Marsh.*

This is a much smaller marsh, and is drained by one main creek. It is enclosed between a fairly recent lateral and the Golf Links, and drains, by a comparatively narrow entry, direct to Brancaster Harbour channel.

(*d*) *Upper Aster Marsh.*

This marsh is exceptional in that in many parts it is lower than would be expected from its position on the island. The sand was put down on its upper part, or Plantago Marsh. As its name implies *Plantago maritima* is very abundant on this marsh. The lower end of the line reached down to the upper part of the main creek draining the marsh, and in this part there is a large spread of *Obione portulacoides*. Farther from the creek the chief plants found are: *Limonium vulgare, Triglochin maritimum, Spergularia media, Glyceria maritima*, and *Plantago maritima*. Near the junction with the smaller line there is much *Armeria maritima*, with *Plantago*, *Limonium*, and *Triglochin*. Station 2A is just inside the *Juncus* belt with *Artemisia*. The shorter line passes through a turf consisting of *Armeria*, *Plantago*, and *Glyceria*, with some *Limonium* and *Triglochin*. There is also a good deal of scattered *Salicornia* spp. The upper stations, 1, 2, and 3, of the main line and some of those of the subsidiary line are in an area of big salt pans (see Text-fig. 3).

ANALYSES OF LINES.

(*a*) *The Long Line on Lower Hut Marsh.*

This line is 484 yards long, and twenty-three sand patches were put down at 22 yards' interval (with one or two minor exceptions to allow for creeks). In this, and every other line, four samples were taken on each patch and the average of these is shown in the column of thickness of sedimentation. The method of taking samples was to use an ordinary metal bicycle pump with the lower end cut off and sharpened. The tube of the pump was driven into the marsh and a clean core obtained, which was pushed out of the pump by the plunger. In this way a minimum of disturbance was made in the sand patch, and all patches can be used for future observations. It was found that the slight compression on the small core resulting from pushing it out of the tube was negligible. As no marsh, in detail, is absolutely flat, and the sand cannot be spread perfectly evenly, the four measurements varied a little,[1] but the average amount of sediment recorded from the four samples is representative of the accretion on any patch.

In reading this and other sections it is important to notice the disposition of the creeks. Their positions are shown on the table, and their general pattern can be seen on the map.

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[1] The average variation in a set of four readings was about, or less than, 10 per cent.

On this particular line it will be noticed that there is little relation, direct or indirect, between the amount of sedimentation at any station and its distance from Norton Creek. (The lower end of the line is near the junction of the main creek near Butcher's Beach and Norton Creek.) The highest figures, e.g., 1·72 cm. and 1·80 cm., are near minor creeks, which on this section are all lined with *Obione*. This is consistent with general observations on the Scolt marshes. Again, the smallest figures are near the two ends of the line. Those at the upper end (stations 1 and 2) are normal, but there is no obvious explanation of those at the lower end, especially as they are in thick *Obione*. It will be noticed also that the whole line is nearly level, the maximum variation in height being a little more than 0·6 of a foot. This, and all other lines were carefully levelled and check-levelled, and the very slight discrepancies resulting (0·06 ft.[1] on this line) were only such as are almost unavoidable in levelling on soft marsh.

Because of the obvious lack of relation of sedimentation with distance from Norton Creek, no attempt has been made to treat the figures statistically as was done in the preliminary article referred to above. A comparison of the figures in Table I and the position of the line (see Text-fig. 2) will suggest that the two major creeks and their tributaries, between which the line lies, have more influence on sedimentation than does mere distance from Norton Creek.

(*b*) *Missel Marsh.*

This line is 418·7 yards long, and there are thirty-seven stations. On account of the numerous small creeks and pans on this marsh, it was quite impossible to attempt even spacing of the stations. Consequently, many were put down at what were judged to be significant points. From station 22 to station 35 a complete record of creeks and pans is impossible in any printed section. This part of the marsh is a relatively new *Aster-Salicornia-Pelvetia* marsh and is cut up by numerous runnels, i.e., small water-courses hardly deserving the title of creek. From stations 1 to 22 the main creeks are indicated in Table II. Station 11 was on the sloping bank of the major creek of this part of the marsh, and the sand had disappeared, hence no record (N.R.) was obtained. Stations 36 and 37 were on the bare soft mud of Norton Creek, and although it is probable that a good deal of mud has accumulated here, it seems that the sand was either washed away or so dispersed as not to be recognizable in the cores obtained.

A glance at Table II will show that although the amount of sedimentation varies a good deal, it is usually highest near creeks. Stations 4, 10, 19, and 21 show this very well. Stations 24 and 25

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[1] This amount (= 0·72 inches) was the greatest discrepancy on a levelled line: it represents no more than the general variation in surface level on almost any square yard of a marsh surface.

TABLE I.—LONG LINE LOWER HUT MARSH.

Station.	*Level.**	*Level referred to Island Zero Level.*	*Distance in yards from Butcher's Beach Creek and Norton Creek.*	*Amount of accretion in cm.*	*Remarks.†*
1	10·00	1·36	484	0·70	
2	9·94	1·30	462	1·18	
3	9·96	1·32	440	1·42	
4	10·05	1·41	418	1·05	
5	9·90	1·26	396	1·40	
					———big creek
6	10·28	1·64	372	1·50	
					———smaller creek
7	9·87	1·23	352	1·15	
					———two little creeks
8	9·82	1·18	330	1·37	
9	9·76	1·12	308	1·68	
10	9·82	1·18	286	1·72	
					———several small creeks
11	9·76	1·12	263	1·45	
					———creek
12	9·86	1·22	242	1·80	
13	10·11	1·47	220	1·50	
14	9·70	1·06	198	1·32	
15	9·87	1·23	176	1·50	
					———creek
16	9·90	1·26	154	1·40	
					———creek
17	9·83	1·19	132	1·30	
18	9·75	1·11	110	1·52	
19	9·65	1·01	88	1·65	
					———creek
20	9·96	1·32	66	1·12	
21	10·04	1·40	44	1·35	
22	9·92	1·28	22	1·52	
					———big creek
23	9·86	1·22	0	1·12	

Junction of Butcher's Beach Creek and Norton Creek.

* In this column No. 1 station on *each* line is taken as 10 feet. The figure 10 is quite arbitrary, but enables the reader, at a glance, to appreciate the slight variations in height of the stations along any line.

† In this, and other tables, the position of the main creeks relative to the stations is shown. The short line indicates a creek *between* two stations, e.g., between 15 and 16 in the above table.

are also consistent, but the creeks here are very small. But once again there is no obvious direct relation between the amount of silt accumulated and linear distance from Norton Creek.[1] Reference

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[1] The levels (Table II) show that the line is rather low between stations 19 and 27. In general, sedimentation is rather higher between these stations, except for Nos. 22 and 23. Rather anomalous figures were obtained at 22, and one very low reading reduced the average considerably. This was the only station of the total number of 104 that gave slightly inconsistent readings.

TABLE II.—MISSEL MARSH.

Station.	*Level.**	*Level referred to Island Zero Level.*	*Distance in yards from Norton Creek.*	*Amount of accretion in cm.*	*Remarks.*
1	10·00	+0·84	418·7	0·20	
2	9·77	0·61	392·3	1·25	
3	9·78	0·62	374	1·25	
4	9·84	0·68	367·7	1·75	
					——small creek
5	9·77	0·61	343·7	1·78	
6	9·63	0·47	330·3	1·75	
7	9·66	0·50	309·3	1·48	
8	9·63	0·47	293·3	1·88	
					——shallow creek
9	9·73	0·57	278	1·70	
10	10·07	0·91	270	2·50	
					——creek *and* major creek
11	8·86	−0·30	243	N.R.	
12	9·46	+0·30	227	1·67	
					——creek
13	9·36	0·20	215·7	1·00	
14	9·35	0·19	212·7	1·72	
15	9·37	0·21	191·7	1·48	
					——creek
16	9·32	0·16	181	1·55	
					——two creeks
17	9·39	0·23	168·3	1·45	
18	9·27	0·11	157·3	1·60	
					——small creek
19	8·96	−0·20	149·7	1·68	
20	9·24	+0·08	146	1·72	
21	9·20	0·04	143·3	1·80	
					——small creek
22	9·26	0·10	138	1·63	
23	9·19	0·03	132·7	1·60	numerous small runnels and salt pans.
24	9·02	−0·14	125·7	2·05	
25	9·09	−0·07	120	2·47	
26	9·19	+0·03	116·7	1·85	
27	9·59	0·43	103·3	1·68	
28	9·56	0·40	96·7	1·70	
29	9·69	0·53	90	1·70	
30	9·57	0·41	81	1·95	
31	9·59	0·43	75·7	1·65	
32	9·90	0·74	69	1·60	
33	9·76	0·60	57·7	1·50	
34	9·58	0·42	48·7	1·60	
35	9·19	0·03	31·3	0·75	
36	7·93	−1·23	10	N.R.	—on margin of isolated patch of *Aster* Marsh
37	7·12	−2·04	0	N.R.	—In mud of Norton Creek.

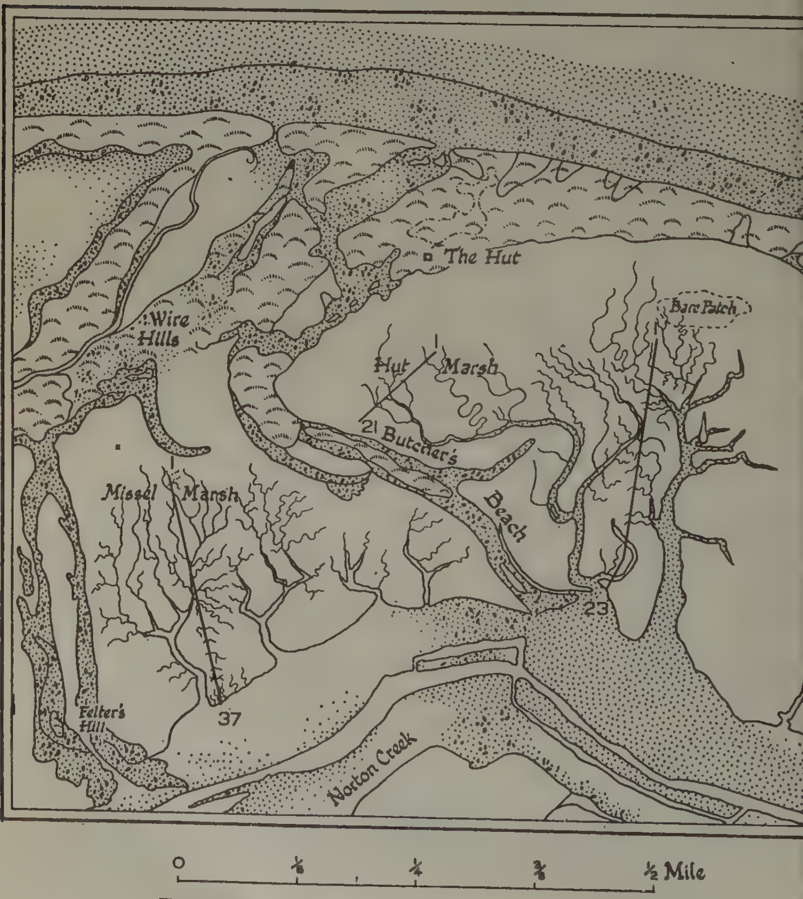
*No. 1 station taken as 10 feet.

to the sketch-map shows better than any description the intricate nature of the creeks—and only the more important ones are indicated along the lower part of the line (see Text-fig. 2).

Missel Marsh is slightly lower in level than is the central part of Hut Marsh (Table 1), and it is this fact which explains the rather higher rates of sedimentation. It is more often covered by the tide, and when covered, the water remains on it for a rather longer time than it does on Hut Marsh.

(c) *Upper Hut Marsh.*

This, western, part of Hut Marsh is appreciably higher than the part represented by Line 1. One major creek crosses it, and it will be seen from Table III that sedimentation rates are considerably higher near this creek than elsewhere. All the stations north of the creek (see map, Text-fig. 2) gave records, though in some



Text-fig. 2.—Lines on Hut Marsh and Missel Marsh.

Table III.—Upper Hut Marsh.

Station.	*Level.**	*Level referred to Island Zero Level.*	*Distance in yards from major creek.*	*Amount of sedimentation.*	*Remarks.*
1	10·00	+2·16	113	0·20	
2	9·98	2·14	103	0·30	
					———small creek
3	10·04	2·20	94·33	0·42	
					———very small creek
4	10·17	2·33	81·66	0·10	
5	10·25	2·41	70·66	0·15	
6	10·27	2·43	62	0·05	
					———very small creek
7	10·09	2·25	56	0·30	
8	10·02	2·18	48·33	0·15	
9	10·01	2·17	36	0·05	
					———very small creek nearer 9
10	9·79	1·95	26	0·18	
11	9·67	1·83	15	0·88	
12	9·36	1·52	6	0·60	
					——major creek: distance measured outwards from this
13	10·04	2·20	5	0·83	
14	10·13	2·29	16·33	0·56	
15	10·07	2·23	26·50	0·26	
					———small creek
16	9·93	2·09	30	0·28	
					———creek
17	10·05	2·21	35·50	0·40	
18	10·27	2·43	44·33	0·18	
					———very shallow creek
19	10·32	2·48	56	N.R.	
					———very shallow creek
20	10·42	2·58	66	still on surface	
21	10·52	2·68	74	still on surface	

*No. 1 station taken as 10 feet.

(e.g., station 4) the sand was barely covered, and 0·1 cm. represents but a rough average. The three stations at the south end of the line gave poor results. They are seldom covered, and the dry sand could easily be scattered by strong winds. There are a few minor creeks crossed by the line, but the linear relation of the amount of sedimentation with increasing distance from a major creek is far better seen on this line than it is in 1 and 2. The smaller number of submergences in any tidal cycle explains fully the small amounts of accretion.

The total length of the line was 187 yards, and there were twenty-one stations.

The plants along this line are generally similar to those along the other line on this marsh, but the greater abundance of scattered masses of *Obione portulacoides* var. *parvifolia* is worth recording. In fact the vegetation generally along this line is less luxuriant and has a " cropped " appearance.

(*d*) *Aster Marsh.*

Two lines at right angles to one another were prepared on this marsh at its upper end, which is often referred to as Plantago Marsh on account of the abundance of that plant. The figure shows roughly the relation of these lines to one another and to the dunes.

The line 2a to 10 is nearly at right angles to the trend of the major creek, and the sand patches are approximately equally spaced except for 1 to 2a and 8, 9, and 10. Sedimentation is greatest near the main creek, decreases in the middle part of the line and increases again near its upper end. As the line is a continuously descending one it is difficult to explain this fact, but in the lower part of the line the abundance of *Obione* probably controls the matter. Stations 2 and 3 are near some very large pans, and for this reason sedimentation would probably be rather anomalous in this part of the line. On account of its distance from the other three lines its exact height relation cannot be given, but it is pertinent to point out that the upper part of the line as well as the line 1 to 1d is covered by the bigger spring tides. The stations 1 to 1d vary but little in height between themselves, and this fact at first sight gives no clue to the decrease in sedimentation towards 1d. This decrease may very possibly be connected with increase of distance from any creeks of importance. Its height may mean that this part of the marsh is almost as frequently submerged as some of the stations in the line 2a to 10, but it is reasonable to suppose that the farther the water has to spread over a marsh from a creek, the less will be the amount of silt deposited at considerable distances from the creek.

The line 2a to 10 is 306 paces (approximately the same number of yards) long ; and the line 1 to 1d, 146 paces. The total number of stations on the two lines is fifteen.

(*e*) *Golf Links Marsh.*

This is a long, narrow marsh enclosed between an eastward pointing shingle ridge and the Golf Links. It is well covered with vegetation, and the line of sand patches was put down about 250 yards from its junction with Brancaster Harbour Channel. The actual line of levels lies just above a chain-gate leading on to the Golf Links.

The chief plant types found along the line are as follow: the main creek is fringed with *Obione*, as is also the other small creek crossed by the line. To north and south of the major creek the chief plants are : *Glyceria maritima*, *Triglochin maritimum*, *Limonium vulgare*,

TABLE IV.—ASTER MARSH.

Station.	*Level.**	*†Distance in paces from major creek.*	*Amount of sedimentation.*	*Remarks.*
2*a*	10·43	306	0·45	in *Juncus* belt
1	10·00	276	0·80	many large pans and "islands" of marsh
2	9·80	234	0·68	
3	9·67	203	0·68	
4	9·38	169	0·30	parallel with and close to a small creek
5	9·16	138	0·50	
				small creek
6	8·89	106	0·56	
				small creek
7	8·39	75	0·85	
				junction of three small creeks
8	8·35	42	1·00	
				small creek
9	8·25	22	0·78	
10	8·46	0	1·60	
				major creek

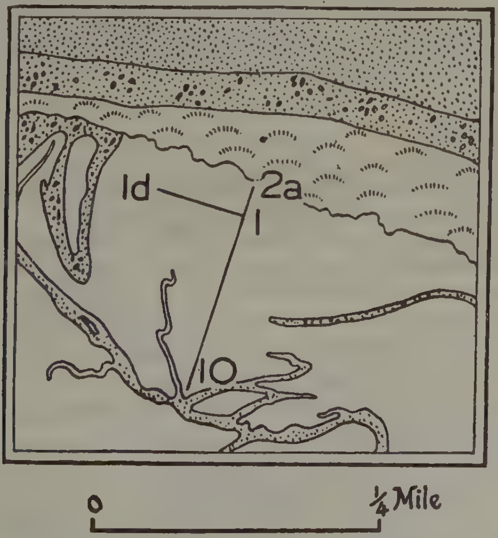
Subsidiary Line.

1	10·00	0‡	0·80	many shallow pans of varying sizes.
1*a*	9·99	36	0·55	
1*b*	10·09	73	0·40	
1*c*	9·97	109	0·35	
1*d*	9·99	146	0·20	

* No. 1 station taken as 10 feet.

† All distances in paces: may be taken approximately as yards.

‡ On subsidiary line distances are measured from station 1 of main line (see Text-fig. 3).



TEXT-FIG. 3.—Lines of Sand on Plantago Marsh.

Salicornia spp., *Spergularia media*, *Aster tripolium*, with *Bostrychia scorpioides*. The amount of *Limonium* increases northwards from near station 7, and at about the same place *Armeria maritima* becomes abundant.

The total length of the line is 222 feet ; unfortunately it cannot be correlated in height with the island marshes on account of the difficulty of levelling across the main channels and the very slippery mud and sand near them.

This marsh affords a simple type as far as sedimentation is concerned. The amount of sediment decreases fairly regularly away from the major creek, and the fact that it is slightly greater at station 8 than at station 7 may possibly reflect the difference in height. But the difference is so small that there is probably little significance in this.

TABLE V.—GOLF LINKS MARSH.

Station.	*Level.**	*Distance in yards from major creek.*	*Amount of sedimentation.*	*Remarks.*
1	10·00	16	0·63	
2	9·72	4	1·45	
			———	major creek : distances measured outward from this
3	9·63	3	1·27	
4	9·96	14	1·02	
			———	creek
5	9·93	25	0·76	
6	9·96	36	0·76	
7	10·34	49	0·61	
8	10·27	58	0·65	

*No. 1 station taken as 10 feet. (This station is 8·57 feet lower than the top of the eastern iron post of the chain-gate near to it.)

CONCLUSION.

Chapman[1] gives the maximum tidal range on the Scolt marshes as 19·5 feet. The mean height of spring tides above the zero line of the island is given as +3·28 feet for 1933. Referred to the zero level of the island, the heights, in feet, of the stations numbered 1 on the two sections of Hut Marsh are 1·36 and 2·16, and that of station 1 on Missel Marsh is 0·84.[2] As certain exceptional tides reach to +4·18 feet above zero level, we may take, for the sake of

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[1] In J. A. Steers, *Scolt Head Island*, Heffer, 1934.

[2] The difference in levels between the stations numbered 1 on (*a*) Lower Hut Marsh, (*b*) Upper Hut Marsh, and (*c*) Missel Marsh are :—

Lower Hut Marsh and Upper Hut Marsh .	0·80 ft.
Lower Hut Marsh and Missel Marsh .	0·52 ft.
Upper Hut Marsh and Missel Marsh .	1·32 ft.

Chapman's figures (*loc. cit.*) would give the height of these three stations, referred to Ordnance Datum, as 8·36, 9·16, and 7·84 ft.

argument, the round figure of +3½ feet as the maximum level for effective spring tides. This implies that stations numbered 1 on each of these three lines are at present roughly 2·14, 1·34, and 2·66 feet below the level of effective maximum submergence. If the present rates of accretion continue to prevail it is but a simple calculation to show how much longer and higher the marshes are likely to grow. It is probable, however, that the rate of accretion will sooner or later decrease, as with increasing height there will be fewer and fewer submergences. The converse of this reasoning is also evident, but far from rigid. If at a given place 2 cm. of silt have accumulated in two years, it does not mean that 30 cm. will have accumulated in thirty years. Allowance must be made for compression, rate of plant growth, and many other factors which obviously cannot be estimated. On the other hand, it does show that marshes develop rapidly, in the geological sense. Further, the rates of accretion measured in this way are consistent with historical evidence, as evidenced, e.g., in Holme Marsh near Hunstanton.[1]

It may be of interest to refer to two other papers—the only detailed ones known to the writer—of marsh accretion :—

1. F. J. Richards "The Salt Marshes of the Dovey Estuary: IV, The Rates of Vertical Accretion" &c. *Annals of Botany*, xlviii, 1934, 225.

2. Niels Nielsen, The Marshes of the Skalling Peninsula, near Esbjerg, Denmark. *Kgl. Danske. Selskab. Biologiske Medd.*, xii, 4.

In conclusion I should like to acknowledge the help given to me by Mr. R. R. Smith and Mr. J. Kettlewood in the no light task of putting down the sand (about 9 cwt. were used). Mr. Smith also gave me invaluable help in checking the bores and carrying out the levelling operations. The mapping of the marsh creeks in Text-fig. 2 was done by Mr. C. A. Fisher on the basis of R. F. Peel's map of the island.

A Dyke Swarm and Crustal Flexure in East Greenland.

By L. R. Wager and W. A. Deer.

As a result of three recent expeditions to East Greenland[2] a remarkable dyke swarm, following closely the general direction of the coast, has been found to run from the neighbourhood of Scoresby Sound to Angmagssalik, a distance of 500 miles. The dykes are dolerites of various kinds and for the most part they are intruded into a thick Tertiary basalt series and the underlying metamorphic complex.[1] At Kangerdlugssuak the dyke swarm is seen to cut two basic intrusions of Tertiary age, but a Tertiary syenite forming Cape Deichman, though lying in the path of the swarm, is free from dykes. Similarly at Kialinek, a hundred miles to the south, the dykes do not enter an intrusion of alkali granite lying in the path of the swarm. The injection of the dyke swarm took place therefore at a late stage in the Tertiary igneous history of the region although some of the more acid plutonic rocks are later still.

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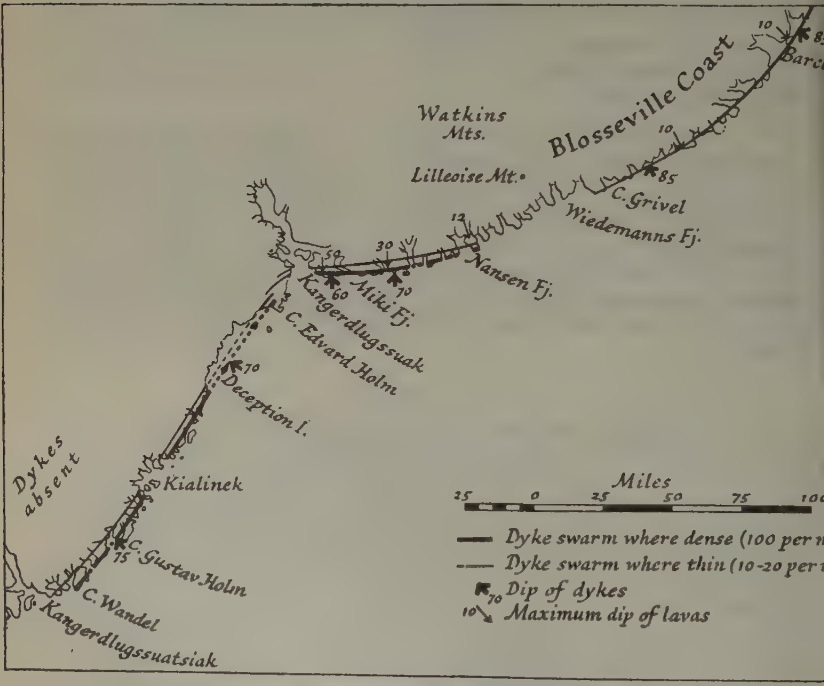
[1] "Some Notes on the North Norfolk Coast from Hunstanton to Brancaster," *Geographical Journal*, lxxxvii, 1936.

[2] British Arctic Air Route Expedition, 1930–31. Scoresby Sound Committee's 2nd East Greenland Expedition, 1932, and the British East Greenland Expedition, 1935–6.

There is a constant relationship between three factors: (1) the dip of the lavas, (2) the density of the swarm, (3) the dip of the dykes. The lavas, where preserved away from the coast, have low dips not exceeding 3°, but as the present coast line is approached the dip increases. The dyke swarm begins where the dip reaches about 10°, while the densest part of the swarm is associated with dips of 30–60°. The change in dip of the dykes is in such a sense that they approach, but do not actually reach, perpendicularity to the lavas.

It is remarkable how closely the dyke swarm is parallel to the general direction of the coast and coincident with it (Text-fig. 1).



Text-fig. 1.—The East Greenland Dyke Swarm.

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[1] Wager, L. R., "Geological Investigations in East Greenland," part i, *Meddel. om Grønland*, Bd. 105, No. 2, pp. 41–4, 1934.

When traced inland the swarm invariably thins rapidly and then dies out altogether. These relationships indicate a connection between the earth movement giving the present orographic conditions and the magmatic and tectonic activity producing the dykes. The maximum density of the dykes found on the outermost headlands varies within wide limits and it is often impossible to decide whether this is due to an original difference in density or to variation in the amount of coastal erosion which has taken place. Thus a dense dyke swarm associated with highly dipping lavas is preserved from Kangerdlugssuak to Nansen Fjord. Farther east, near the Lilleoise Mountains, which are formed of Tertiary plutonic intrusions, the coast bends inwards slightly, and the maximum dip of the lavas is 3°; here the dyke swarm is missing. If this is due to erosion it is difficult to understand why this part has been especially susceptible. It seems more probable that because of some general sagging in the crust the dyke swarm and related structures have been carried below present sea-level. From Cape Grivel to Barclay Bay there is a moderate dyke swarm and the lavas at the outer coast have a dip of 10–12°. Still farther north, about Cape Dalton, the usual arrangement is modified for a short stretch by faulting which came after the dyke injection.[1]

South of Kangerdlugssuak the Tertiary basalts are only preserved as rare remnants, and the dyke swarm mainly cuts through the Metamorphic Complex. The swarm is dense on Flat Island and Deception Island, but is thin or absent on the nearby mainland. The dense swarm can be traced as far as Cape Wandel. Here the coast is stepped north-westward and farther south the swarm becomes thin until, in the Angmagssalik District, there are only a few dykes per mile which, however, are still in the regional direction, N.N.E.–S.S.W. The lavas, where preserved, dip seawards; complementarily the dip of the dykes on the outer coast averages 75° landwards. These two facts suggest that, as north of Kangerdlugssuak, the dyke swarm is associated with an abrupt seaward tilt of the crust.

At Kangerdlugssuak the dyke swarm changes in direction through 50° (Text-fig. 2). At an early stage in the mapping it was expected that the apparent change in direction would prove to be the result of the intersection of two separate dyke swarms but later this view was found to be wrong. The E.W. part of the swarm, present in force to the east of Kangerdlugssuak, is represented by only a dozen dykes in this direction on Amdrup Point and farther west dykes become very rare. In the same way the dyke swarm south of Kangerdlugssuak, which has a N.N.E. direction, does not continue to the N.E. of the fjord. Many dykes which are more or less vertical are found on Kraemers Island; these are radiating from the turning

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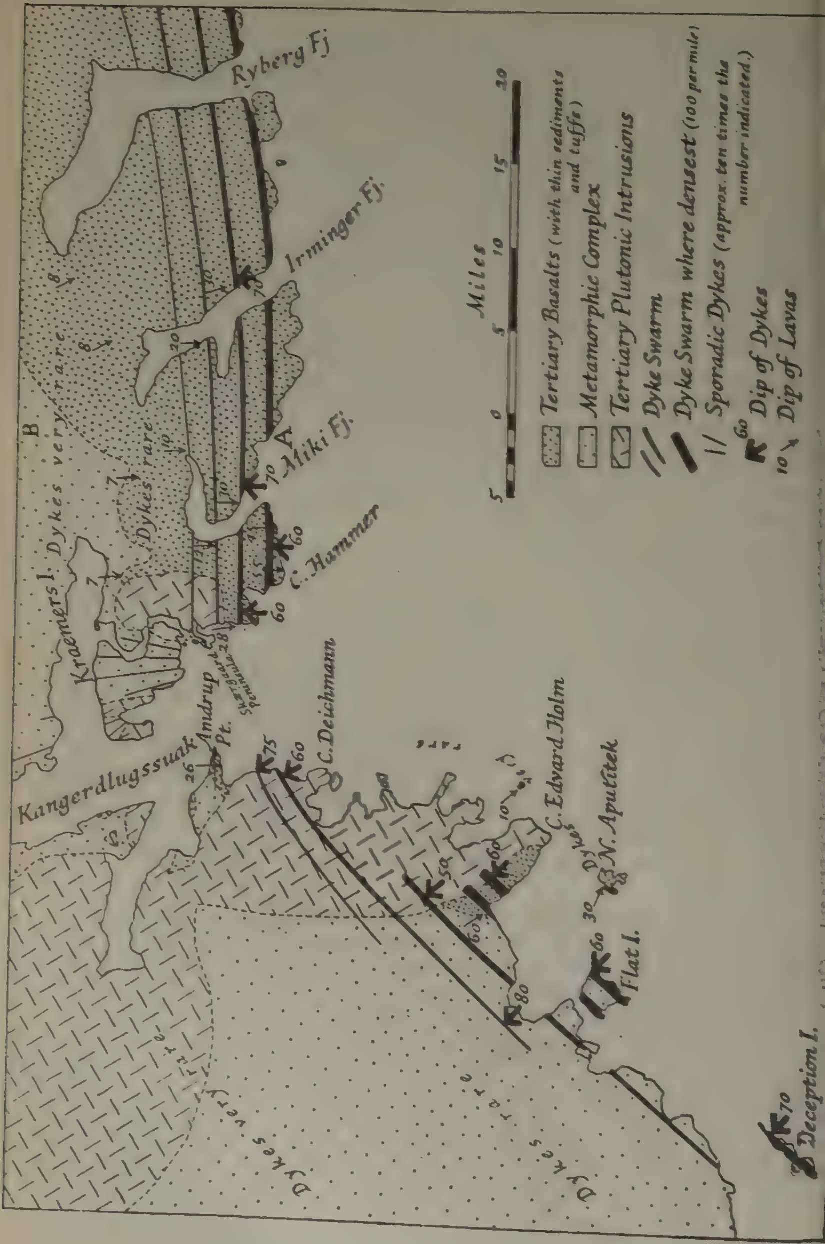
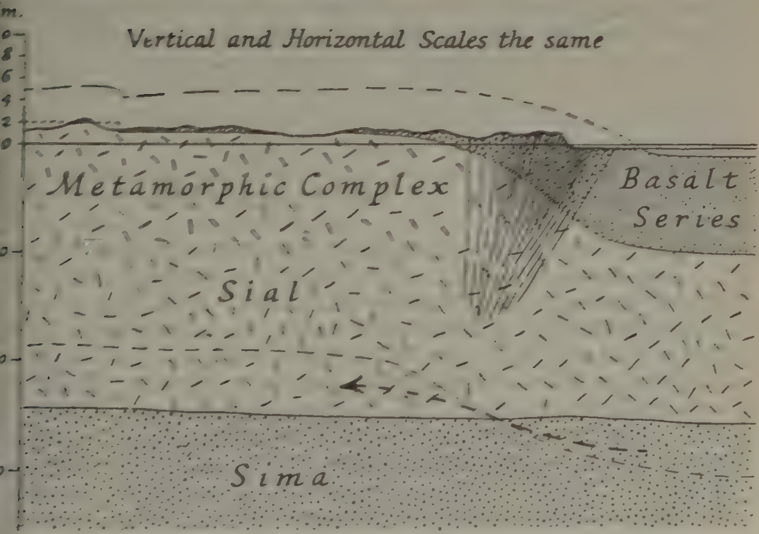
[1] Wager, L. R., "Geological Investigation in East Greenland," part ii, *Meddel. om Grønland*, Bd. 105, No. 3, pp. 11–13, 1935.


Ryberg Fj
Irminger Fj.
Miki Fj.
A
B
C. Hammer
Kraemers I.
Dykes very rare
Dykes rare
Kangerdlugssuak
Amdrup Pt.
Skærgaard Peninsula
C. Deichmann
C. Edvard Holm
Dykes
N. Aputitek
Flat I.
Deception I.
Dykes very rare
Dykes rare
Miles
5 0 5 10 15 20
Tertiary Basalts (with thin sediments and tuffs)
Metamorphic Complex
Tertiary Plutonic Intrusions
Dyke Swarm
Dyke Swarm where densest (100 per mile)
Sporadic Dykes (approx. ten times the number indicated.)
60 Dip of Dykes
10 Dip of Lavas

point of the main swarm and they become rare ten miles farther N.W. The dyke swarm actually changes its direction in a curve having a radius of about ten miles. Where the curvature is taking place there is also a side stepping or "en echelon" arrangement.

Dyke swarms have been universally ascribed to tension in the crust. In the present case tension is associated with flexuring which has controlled the direction and position of the swarm and indeed has probably been the immediate cause of it. It is clear from the dips of the lavas and underlying sediments (Figs. 1 and 2) that this part of East Greenland has undergone a powerful flexuring movement which has produced the Denmark Strait on the downthrow side and the highest mountain country in Greenland on the other. Apparently the flexure or monocline took place during the later stages of the East Greenland Tertiary igneous activity, and the tension developed in the convex part of the flexure produced successive fractures which were occupied by the basaltic magma underlying the whole region (Text-fig. 3). The direction in which



Text-fig. 3.—Vertical section along longitude 77° 25′ (A–B of Text-fig. 2), showing the observed thickness of the lavas and the relation of the dyke swarm to the crustal flexure. The presumed position of the lower surface of the sial after extrusion of the lavas (broken line) is shown modified by migration of sial in the direction of the arrow. Making the usual assumptions about densities, the migration of sial shown is sufficient to compensate only half the present elevation of the inland region.

tension cracks would most easily form would be approximately perpendicular to the tilted lavas and this accounts for the observed connection between the dip of the dykes and the dip of the lavas. It was at first thought possible that the dykes were injected into vertical fissures before the flexuring and that their present dip was the result of later tilting of the lavas and the included dykes, but since the dyke swarm only occurs where the flexure is found, and since the density of the swarm is proportional to the intensity of the flexure, there seems no reasonable doubt that the flexuring and dyke injection took place simultaneously and are related in origin. The formation of the dyke swarm must have been a slow process, for composite dykes are rare, although multiple dykes, in the sense used originally by Harker, are common enough. This implies that after each injection of basalt there was time for it to cool to a solid rock before the tension had accumulated sufficiently to form a new fracture.

There is considerable divergence in the views held on the precise nature and the origin of the tension producing a dyke swarm. Sollas and McHenry, [1] writing in 1896, pointed out that the direction of the British Tertiary dyke swarm is the same as the direction of the compressive forces which have produced the Tertiary folding in South England. The dykes are in the direction which "on mechanical principles they might be expected to take, if they were produced by the same thrusts as those which determine the structure of the southern part of the country". The direction of the regional dykes in Skye is approximately at right angles to the dip of the lavas and Harker [2] has suggested that the dyke swarm may have had as its immediate cause a feeble flexuring of the crust. He tentatively followed Bertrand in considering that the tension and downsinking producing the flexure was the result of events of large order such as the formation of the Atlantic; Clough, Maufe, and Bailey have accepted a similar view of the origin of the Etive dyke swarm, though direct evidence of flexuring is not there available.[3] Another view of the origin of the British Tertiary dyke swarm, advocated by Richey, [4] is that it is the result of tension produced by magmatic pressures in a huge reservoir extending in a N.N.W.–S.S.E. direction and approximately co-extensive with the dyke swarm. This is roughly the view developed long ago by Hopkins and quoted by Geikie in the *Ancient Volcanoes of Great Britain* (pp. 177–8). In the case of the East Greenland dyke swarm the immediate cause is a powerful flexuring of the crust which is so recent as to be responsible for the present coast line and the inland mountains on the one hand, and the Denmark Strait on the other. The flexure must be ascribed to relative vertical movements combined with regional tension and the origin of this must be sought in some of the major processes taking place in the earth's crust.

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[1] Sollas and McHenry. "On a volcanic neck, of Tertiary age, in the county of Galway." *Trans. Roy. Irish Acad.*, vol. xxx, part xix, 1896, 729–731.

[2] Harker, A., "The Tertiary Igneous Rocks of Skye," *Mem. Geol. Survey of United Kingdom*, 1904, pp. 305 and 411–13.

[3] Clough, C. T., Maufe, H. B., and Bailey, E. B., "The Cauldron Subsidence of Glen Coe," *Quart. Journ. Geol. Soc.*, lxv, 1909, 673–5.

[4] Richey J. E., "Tertiary ring structures in Britain," *Trans. Geol. Soc. Glasgow,* vol. xix, part i, 1932, 135.

The speculative views on the origin of tension and vertical movements in the crust which have been put forward by Joly, Wegener, and now by Holmes in his convection theory, have a bearing on the origin of dyke swarms in general, but they will not be discussed in the present paper. Instead we offer certain speculations—made possible by the simplicity of the geological structure of this part of East Greenland—on the origin of this particular dyke swarm and associated flexure. Immediately prior to the outpouring of the Tertiary basalts the region consisted of a Pre-Cambrian shield worn down to about sea level. The same is true of the better-known basalt area of Disco Bay in West Greenland and indeed it may hold for the rest of the country although there is little definite information available at present. The basalts poured out in the Kangerdlugssuak region accumulated to very different thicknesses in different places. Round the mouth of Kangerdlugssuak 7 km. of basalts and tuffs are still preserved and a considerable thickness has undoubtedly been eroded away. In the Prince of Wales Mountains, fifty miles inland, the observed thickness is 2 km. The Ice Cap is there covering an apparently unmodified plateau and probably little or none of the lavas have been removed by erosion. In a geosyncline, tectonic or magmatic movements in the crust are required to provide space for the accumulation of the thick series of light, shallow water sediments, but there seems no reason why plateau basalts should not be laid on the crust and form an additional load just as an ice sheet does. This additional load of basalt should, like an ice sheet, produce downsinking of the crust. Assuming that the isostatic effect produces an approximation to hydrostatic equilibrium in the crust and also that no complication arises from the migration of lower crustal layers, then the upper surface of the basalt should continually approach the level of the surface on which the basalts began to be poured out, in this case approximately sea level. Where the thickness of the basalts is 7 km. the subsidence of the pre-Tertiary peneplain should approach this value, and where the thickness of the basalts is only 2 km. the subsidence should be correspondingly less. Between these two points a feeble flexure of the crustal rocks would occur.

The actual flexure found in East Greenland is more intense than this, and moreover a dome-shaped uplift with its centre some twenty miles inland and with dips reaching 3° on its flanks has raised the base of basalt series 2½ km. above sea-level (Text-fig. 3). If the region is in approximate isostatic equilibrium such an uplift suggests a concentration of sial below it. It seems possible that where the original sial crust has been buried beneath at least 7 and probably 10 or more kilometres of basalt that it has become mobile and has migrated outward from the place of deepest burial so that the sial-sima junction approaches parallelism with the geoid. Such migration of sial to the west (as shown in Text-fig. 3) may form part, but not the whole, of the support for the dome from which the high coastal mountains are formed. In the same way migration of sial from under the Denmark Strait to the east may have provided the sial support for Iceland which Hawkes and his co-workers have postulated.[1] The removal of some of the sial layer beneath the Denmark Strait would allow the surface of the basalts to sink below sea level. The strait is for the most part quite shallow, but there is evidence that recent deposition of sediments is the cause. If a process of this sort actually occurs it is capable of extending the ocean basins, and indeed may have been, in very early times, a factor in their formation.

CORRESPONDENCE.

CAIRNSMORE OF FLEET GRANITE.

Sir,—There is an unfortunate error in our paper on the Cairnsmore of Fleet granite published in the Geological Magazine for July, 1937. On page 296 the position of the monchiquite dyke [74] is wrongly given. It occurs in the Little Water of Fleet intrusive in the granite about 40 to 50 yards from the margin of that rock. As this rock is an exceptional one, it is desirable to make this correction.

C. I. Gardiner.
S. H. Reynolds.

The University,
Bristol.

A PLEISTOCENE STRAND LINE IN THE VALE OF YORK.

Sir,—Mr. Sidney Melmore, writing to the Geological Magazine for October, 1937, quotes part of a paragraph of mine (*Proc. Yorks. Geol. Soc.*, xxiii, 1936, 115) which leads him to infer "the spectacle of a river terrace some 40 feet below its presumed base level". Had he considered the rest of the paragraph he might have avoided this misunderstanding. Mr. Melmore appears to be confusing the base level of "erosion" which was at that time controlled by the 100 Foot Submergence and the base, or lowest possible level of "deposition" which was determined by the depth of the river valley already in existence. "Certain patches of sand—which appear to be of Higher Terrace age" do indeed lie below the 100 Foot Strand Line at Ferrybridge; they were deposited under water in the submerged area which extended several miles farther upstream.

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[1] Cargill, H. K., Hawkes, L., and Ledeboer, J. A., "The Major Intrusions of South Eastern Iceland," *Quart. Journ. Geol. Soc.*, lxxxiv, 1928, 534.

Mr. Melmore dismisses my correlation of Airedale terraces as ambiguous and likely to lead to serious confusion. His simple alternative is to ignore the existence of a Lower Terrace and, apparently, to include the Higher Terrace in a group of "20 Foot terraces" of late Hessle age, presumably common to other dales, which must "fan out into the sands and silts which fill the Vale of York up to about 50 feet O.D." Firstly, a reference to the Ordnance Survey maps will show that there are no such 50 foot deposits in the Vale of York contiguous to lower Airedale. Secondly, if the Higher Terrace is of "late Hessle age", what is the age of the later Lower Terrace, which, far from being absent, is a bulky fluvio-glacial deposit contemporary with the last Dales glaciation? Thirdly, where does the Leeds *Hippopotamus* fit into this scheme? I have referred to Mr. Melmore's book, p. 88, and do, of course, give him credit for the conclusion that this animal lived in interglacial times. But why does he correlate it with the Woodlesford deposits, which are in the Higher Terrace ("20 Foot Terrace" of Mr. Melmore), and therefore, on his showing, late Hessle?

May I deprecate the use of such meaningless terms as "10 Foot Terrace" and "20 Foot Terrace"?

WILFRID EDWARDS.

YORK.
6th December, 1937.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY

4th November, 1937.

(1) "Scawtite pseudomorphs after spurrite at Scawt Hill, Co. Antrim." By Professor C. E. Tilley.

(2) "The occurrence of acmite in the riebeckite-microgranite of Mynydd Mawr, Caernarvonshire." By Dr. S. R. Nockolds.

The previously unidentified mineral, occurring as colourless or pale yellow acicular crystals, in the riebeckite-microgranite of Mynydd Mawr, is now shown to be acmite. As it is quite plentiful in the thin sections examined it is suggested that riebeckite-acmite-microgranite would be a more correct term for the rock.

(3) "The composition and paragenesis of the hornblendes of the Glen Tilt Complex, Perthshire." By Dr. W. A. Deer.

Hornblendes are the dominant ferromagnesian minerals in the intermediate and basic rocks of the Glen Tilt Complex. Nine hornblendes from the diorites, appinites, hornblendite and hornblende-schist xenoliths, and the injected hornblende-schist of the country rock have been examined chemically and it is considered that the results may give some indication of the history and mode of formation of the rocks in which the hornblendes occur and will also indicate the possible range of composition of common amphiboles within the diorites and related rocks of a single complex. Large differences in composition are found between the early and the later hornblendes.

(4) "Russellite, a new British mineral." By Mr. F. A. Bannister and Dr. M. H. Hey.

The new mineral, which occurs sparingly at the Castle-an-Dinas Wolfram mine, St. Columb Major, Cornwall, is a mixed crystal of bismuth and tungstic oxides approximating to the composition $Bi_2O_3.WO_3$. The X-ray data indicate that it is not a bismuth tungstate as at first thought. The minute crystals are tetragonal, a 5·42, c 11·3 Å., space group D_{2d}^{12}, and the repeat is $(Bi_2, W)_4O_{12}$. A description of the occurrence and accompanying minerals by the discoverer, Mr. Arthur Russell, is appended.

(5) "A re-examination of cliftonite." By Dr. M. H. Hey.

At the suggestion of Dr. H. Berman, an X-ray examination has been made of cliftonite (L. Fletcher, 1887). It proves to consist of graphite micro-crystals arranged with their c-axes parallel to the three tetrad axes of the cubes. This suggests that it is probable that the crystals are pseudomorphs, but the original mineral has not been identified.

ANNOUNCEMENT.

Clough Memorial Research Fund.

This fund was instituted in 1935 for the purpose of encouraging geological research in Scotland and the North of England. The North of England is defined as comprising the counties of Northumberland, Cumberland, Durham, Westmoreland, and Yorkshire. Under the terms of administration of the fund a sum of approximately £30 is available annually.

Applications for grants are invited for the period, 1st April, 1938, to 31st March, 1939. These applications should state :—

1. The nature of the research to be undertaken.
2. The amount of grant desired.
3. The specific purpose for which the grant will be used, e.g. travelling expenses, maintenance in the field, excavation of critical sections, etc.
4. Whether any other grant-in-aid has been obtained or applied for.

Applications must be in the hands of the Secretary, Clough Research Fund Committee, Edinburgh Geological Society, Synod Hall, Castle Terrace, Edinburgh, not later than 1st February, 1938.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXV.

No. II.—FEBRUARY, 1938.

ORIGINAL ARTICLES.

On *Camerina petri* M. G. Rutten and *Nummulites striatoreticulatus* L. Rutten.

By R. Wright Barker.

(PLATE III.)

DURING recent work on a collection of *Camerinidae* from Mexico the species recently described by M. G. Rutten, from Cuba, were considered in some detail, since Cuban and Mexican foraminiferal faunas show close affinities. No Cuban species of *Camerina* or *Operculina* were found in the Mexican Tertiary material, but some interesting points were discovered regarding *Camerina petri* Rutten.

A careful examination of the original description and of material from Cuba in the possession of the writer showed that this species is identical with *Nummulites striatoreticulatus* L. Rutten, described in 1928 from the Upper Eocene of Curaçao. This provides additional evidence as to the Upper Eocene age of at least part of the Seroe di Cueba Limestone, which is also supported by the discovery of *Operculinoides nummulitiformis* (L. Rutten) in the Jackson Eocene (Tantoyuca Formation) of Mexico.

Furthermore the name *petri* is preoccupied by *Nummulites petri* Mancini (1928, *Sped. Ital. Filippi Bologna*, **2**, b., p. 263, pl. xxvii, fig. 2, from the Eocene of Ladak, India), thus necessitating a new name for the Cuban species. Rutten's species is now as follows, according to the writer's opinion :—

CAMERINA STRIOTORETICULATA (L. Rutten), Pl. III, figs. 1–5.

1928. *Nummulites striatoreticulatus* L. Rutten, *Proc. Konink Akad. v. Wetensch.*, xxxi, No. 10, 1068–9, figs. 41–50, pl. figs. F, G, H, I (not fig. J) (U. Eocene, Curaçao).
1929. *Camerina* sp. Vaughan, *Journ. Paleont.*, iii, 377, pl. xl, fig. 1 (U. Eocene, Jamaica).
1935. *Camerina petri* M. G. Rutten, *Journ. Paleont.*, ix, 530–1, pl. lix, figs. 1–5, text-fig. 2 (Upper Eocene, Cuba).
non *Nummulites petri* Mancini, 1928, *Sped. Ital. Filippi Bologna*, **2**, b., p. 263, pl. xxvii, fig. 2 (Eocene, India).

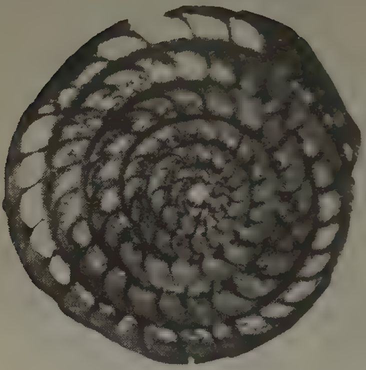
L. Rutten describes *Nummulites striatoreticulatus* as characterized by " small thickness, closely serried whorls, and very long chambers ", and later remarks that the " septa . . . always appear to run radially with slight irregular bends " . . . also " of real granulae absolutely nothing is to be seen ; occasionally I saw some faint thickenings on the septa ". He furthermore gives the dimensions of a single microspheric form as diameter 10·0 mm. and thickness 2·5 mm. in comparison with 3·8 and 4·7 mm. and 1·3 to 1·7 mm. for the megalospheric form. M. G. Rutten, in describing *Camerina petri*, gives the test as being " of medium size, lenticular, involute, radiate ; granules present or absent on the central part of the test ; costae gently curved ; several small pillars in the central part of the test. . . ."

It is certain from observations made by the writer that M. G. Rutten included microspheric forms and megalospheric forms together in his table for *C. petri*, thus increasing the close similarity between the two species. The figures seem to show very clearly that we are dealing with a single species showing only minor differences in the two areas, but we have the following figures which serve as an additional check :—

Species	Diameter	Thickness	No. of whorls	No. of chms. in final whorl
Camerina striatoreticulata (L. Rutten)	4–5 mm. (1 microspheric 10 mm.)	1·3, 1·7 (2 sp.)	5–6½	22–28
Camerina petri M. G. Rutten.	3–8 mm.	1·1–3·2 mm.	4 (young)–8	20–30
Camerina petri (specimens in possession of writer).	5–10 mm.	1·5 to 3·0 mm.	7–7½	22
Camerina sp. Vaughan.	6·25 mm.	1·85 mm.	7	unknown

Also the diameter of the initial chamber is given as 200–320μ for *C. striatoreticulata* and 120–300μ for *C. petri*.

The figures of M. G. Rutten are taken from sections cut in the median plane, and the writer's experience, as also Professor L. Rutten's, show that in such sections the " anteriorly directed processes " considered characteristic of the species are not visible. They are well shown, however, in the Cuban specimens, as may be seen in Pl. III, Fig. 5, and there seems no reason to doubt that these specimens are the same as M. G. Rutten's *C. petri*. These " processes " are considered to be reticulations in the alar prolongations of the septa as figured by Carpenter (*Introduction to the Foraminifera*, 1862, pl. xviii, fig. 9), thus making *Camerina striatoreticulata*



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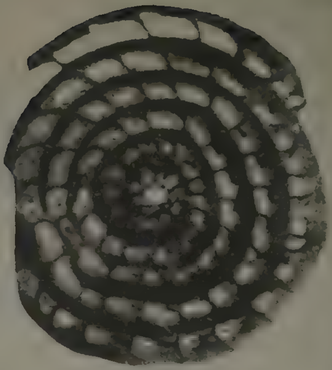

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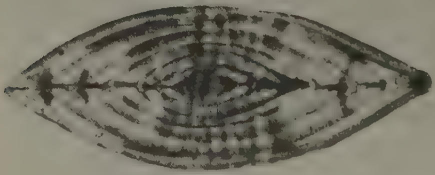

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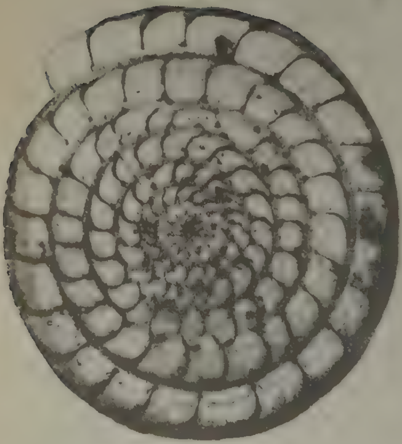

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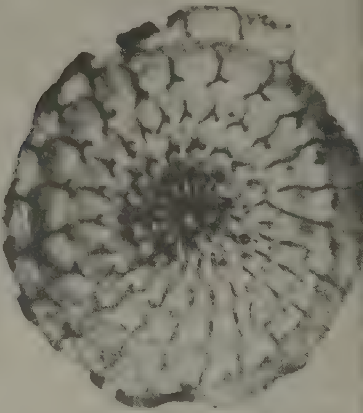


5 x10

CAMERINA STRIATORETICULATA (Rutten).

one of the forms grading between the sinuate and reticulate (subreticulate) groups.

The species may very well prove a valuable guide to the Caribbean Upper Eocene, occurring as it does in Curaçao, Jamaica, and Cuba.

REFERENCES.

RUTTEN, L., 1928. "On Tertiary Foraminifera from Curaçao," *Kon. Akad. w. Wetensch., Amsterdam, Proc.*, xxxi, 1061–1070, 1 plate.

RUTTEN, M. G., 1935. "Larger Foraminifera of Northern Santa Clara Province, Cuba," *Journ. Paleont.*, ix, 527–545, pls. lix–lxii.

VAUGHAN, T. WAYLAND, 1929. "Additional New Species of Tertiary Larger Foraminifera from Jamaica," *Journ. Paleont.*, iii, 373–382, pls. xl, xli.

EXPLANATION OF PLATE III.

FIGS. 1, 2.—*Camerina striatoreticulata* (Rutten). Reproductions of Rutten's original figures I and H (on plate).

FIGS. 3–5.—*Camerina striatoreticulata* (Rutten). Photographs of sections of material from the U. Eocene of Cuba (previously referred to *Camerina petri* M. Rutten). In the collection of the author.

Transfusion Phenomena in Lamprophyre Dykes and their bearing on Petrogenesis.

By DORIS L. REYNOLDS.

With Micro-chemical Analyses by Dr. Edith Kroupa.

1. INTRODUCTION.
2. THE EVIDENCE.
    (*a*) Evidence from a Dyke near Kircubbin, Ards Peninsula, Co. Down.
    (*b*) Evidence from the Newmains Dyke, Dumfriesshire.
    (*c*) Comparable Evidence from other Lamprophyre Dykes.
3. THE PETROGENESIS OF THE CALEDONIAN LAMPROPHYRE SUITE.
4. SUMMARY OF CONCLUSIONS.
5. BIBLIOGRAPHY.

1. INTRODUCTION.

IN the hornblendite which forms the rocky outcrops of Port Easdail in the Island of Colonsay, quartzite xenoliths exhibiting various stages of conversion to syenite and appinite are spectacularly displayed. In some instances the residual quartzite of the xenoliths is rimmed by a pink felspathic zone of micropegmatite and/or syenite; in others the residual core is rimmed successively outwards by a felspathic zone and a zone of appinite; whilst in others, again, completely replaced xenoliths are now represented by felspathic patches of syenite or appinite. In 1936 I described these phenomena and the manner in which veins of syenite or appinite extend into the hornblendite from the metasomatized rims of the xenoliths. It was then shown that the process of metasomatism, leading up to magmatization, was one in which various constituents, principally sodium, potassium, and aluminium (or their oxides), migrated from the hornblendite magma into the xenoliths. After the conversion of the quartz of the xenoliths to felspar, the material for forming ferromagnesian minerals was introduced.

It was only after examining these striking examples of metasomatism that I recalled the pink felspathic patches and schlieren, often associated with quartz, that characterize many of the lamprophyre dykes of the Ards Peninsula, Co. Down, Ireland. Indeed, at the time of investigating these dykes (1931), in harmony with the ideas then prevalent, I regarded much of the quartz, with its associated felspar, as the infillings of vesicles. Having gained experience from the Colonsay exposures, it became desirable to re-examine some of the Ards lamprophyre dykes, and the purpose of the present communication is to present evidence from one of them which is closely similar to, though less spectacular than, that recorded from Colonsay. Although attention is thus focused on a particular dyke, the phenomena are equally well demonstrated by other members of the Ards lamprophyre swarm. Similar evidence from lamprophyre dykes of other areas is also here recorded or cited, and the significance of the phenomena is discussed in relation to the petrogenesis of the British Caledonian lamprophyres.

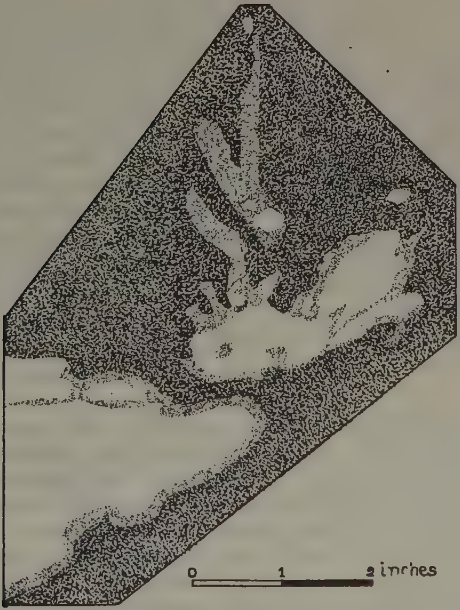
2. The Evidence.

(*a*) *Evidence from a Dyke near Kircubbin, Ards Peninsula, Co. Down.*

About 260 lamprophyre dykes, belonging to the Caledonian swarm, outcrop along the coasts of the Ards Peninsula, where they are intruded into Silurian greywackes and shales (Reynolds, 1931). The particular member which is to be described outcrops approximately half a mile south of Kircubbin, on a small promontory forming the southern shore of Doctor's Bay, on the eastern side of Strangford Lough. The dyke is somewhat winding, but shows an average north-north-easterly strike and dips towards the west-north-west, cutting across both the strike and the dip of the sediments. It is exposed for a distance of about 50 yards along its strike, and can be seen to be of variable width, in places expanding to 15 or 20 feet. Towards the southern limit of its exposure it becomes sheet-like in character. In several parts of its exposed course it ramifies and shows intercalations of sediments. Neither the contact sediments nor the intercalated lenses of sediment show appreciable contact alteration.

The dyke is multiple and it is the eastern component, about 5 feet wide, that is of special interest in the present connection. The central part of this member of the intrusion is in places crowded with xenoliths of vein quartz. Even where the xenoliths are specially concentrated, the marginal parts of the enclosing dyke-member remain free from xenoliths through a width of about a foot on the western side and 8 inches on the eastern side. The xenoliths measure up to about 4 inches across and many of them are angular in shape. The portion of the dyke in which the xenoliths are located tends to be coarser in grain than the marginal parts.

The xenolith-bearing member of the intrusion is noticeably heterogeneous in character, there being rapid variation from fine- to medium-grained and from melanocratic to leucocratic rock. This heterogeneity is largely due to the presence of felspathic veins and patches which can be related to the quartz xenoliths. Many of the quartz xenoliths exhibit narrow pink felspathic replacement rims. The replacement origin of the rims is evidenced by the fact that they are sharply bounded, not only against the residual quartz but also, in many instances, against the enclosing lamprophyre. From many of these rims felspathic veinlets extend through the lamprophyre (Text-fig. 1). The felspathic veinlets vary from narrow (5 mm. or less) pink veins to broader (up to 2 cm.) pinkish grey veins, both varieties being seen to emerge from the felspathized margins of quartz xenoliths. The field evidence makes it clear that



Text-fig. 1.—Quartz xenoliths (unshaded) with felspathic replacement-rims (lightly shaded) in vogesite (heavily shaded) south of Kircubbin. Rheomorphic felspathic veins extend from the replacement-rims into the vogesite.

(*a*) the felspar resulted from the metasomatism of quartz xenoliths, and (*b*) the felspathic material so developed finally became rheomorphic (Backlund, 1937, p. 234).

In many instances a quartz xenolith with a narrow felspathic rim forms the nucleus of a relatively coarse-grained patch of leucocratic lamprophyre. On the other hand, similar coarse-grained leucocratic patches and small felspathic patches can be found that contain no visible xenolithic core. In these latter instances it can be inferred that the patches have resulted from complete replacement of xenoliths.

Petrography.—In thin section the lamprophyre is found to be a member of the vogesite group (Rosenbusch, 1907), being characterized by brownish green hornblende and alkali-felspar. It belongs to vogesite type B, as described in 1931 (Reynolds, 1931, p. 145), in which euhedral hornblende is embedded in a matrix of anhedral felspar. In its coarser parts it is closely similar to the analysed specimen of vogesite type B (see Table II, No. 1). The hornblende ($Z \wedge c = 23°$; optically negative; 2V close to 90°) varies in habit in different parts of the dyke. In the coarser-grained patches it is characteristically short-prismatic, in which case it not infrequently exhibits re-entrants, inclusions of the felspar, and " splitting apart " along cleavage planes. In the fine-grained patches it is acicular in its development, individual crystals cutting across the boundaries of adjacent felspar individuals. Outgrowths of tremolite and/or actinolite are common on the terminal faces of the hornblende.

The felspar comprises both a soda-potash-felspar and albite, probably usually in roughly equal amounts, although sometimes albite appears to be the more abundant. The felspar shows a brown pigmentation due to the presence of minute particles of what appears to be haematite. It also sometimes contains sericite.

Small crystals of diopside are present. They are commonly rimmed by a narrow zone of colourless chlorite, and are almost invariably much dissected by replacement veinlets of this mineral.

A small amount of quartz is intergrown with the felspars, and green chlorite, epidote, and calcite are common constituents of the rock. The green chlorite often replaces hornblende. The common accessories are iron-ore and apatite, the latter occurring as fine needles crossing the boundaries between the other minerals.

The quartz xenoliths consist solely of interlocking grains of quartz, and thus appear to be vein quartz. The felspathic rims, which margin the residual cores of the xenoliths, show considerable variation, but they consist essentially of alkali-felspar, both albite and potash-felspar, and quartz, thus resembling the leucocratic part of the lamprophyre itself. The rims are always sharply bounded against the quartz and in places replacement veinlets extend from them into the xenoliths. Moreover, felspar sometimes extends as an intergranular film from the rim into the xenolith, thus evidencing the replacement origin of the felspar. In some instances the rims are sharply bounded against the lamprophyre, whereas, in other examples, they show rapid gradations to the dyke rock.

The texture of the rims varies from one example to another. In some instances it is orthophyric, the felspars exhibiting rectangular sections, whereas in others the felspars are anhedral. The grain size is also variable, and in many instances it is finer than that of the main rock. Quartz is usually present in small but variable amount.

Some of the rims are heavily charged with chlorite and calcite, and it can usually be demonstrated that the calcite replaces the felspar, since the former contains isolated but optically continuous fragments of the latter. The chlorite-rich rims are similar to many decomposed-looking lamprophyres. Chlorite sometimes margins the rim against the residual quartz of a xenolith, and both chlorite and calcite extend into and replace the quartz. In the latter case the calcite has often developed along the intergranular boundaries of the xenoliths, but sometimes it extends into individual quartz grains along rhombohedral planes. In some instances twig-like growths of epidote have developed in the rim.

In some examples, where the felspathic rim is narrow, it is rimmed against the lamprophyre by small pseudomorphs, in which calcite and almost colourless chlorite are associated; each pseudomorph is margined by a narrow zone of pale chlorite. In a few cases residual cores of diopside within the pseudomorphs evidence the original nature of the latter.

The felspathic veins (many of which are seen to emerge from the felspathic rims) exhibit sharp or rapidly merging margins. The narrow pink veins are found in thin section to be fine-grained—considerably finer-grained than the lamprophyre—and to consist essentially of alkali-felspar, both albite and potash-felspar, with quartz filling the interspaces. The felspars usually give roughly rectangular sections, but some of them are anhedral. They are heavily clouded with dust-like material—probably haematite. Sparse acicular crystals of hornblende are sometimes present and needle-like apatite is the most common accessory. Chlorite and calcite are present in small amount only.

The broader pinkish grey veins are considerably coarser in grain than the lamprophyre. They consist essentially of an intergrowth of anhedral felspars, both albite and potash-felspar, which are again strongly pigmented with haematite powder. They are less rich in quartz than the veins just described and considerably richer in mafic material. The latter consists of chlorite and twig-like groupings of fine granules of epidote. Needle-like apatite is very abundant in these veins.

The rock forming the pinkish grey veins is similar to that composing the felspathic dykes (e.g. the analysed alkali-felspar-porphyry of Table V) which are so commonly associated with the Caledonian lamprophyres.

Chemistry.—A micro-chemical analysis of a typical felspathic rim from a quartz xenolith collected at the southern end of the exposed part of the Kircubbin dyke has been made by Dr. Edith Kroupa, and the results, together with the norm, are shown in Table I. An analysis of a vogesite closely resembling the lamprophyre under discussion, and located only a short distance away from it in the field, is repeated from the 1931 paper in Table II, No. 1. In common with the lamprophyres in which they are found, the felspathic rims of the quartz xenoliths contain calcite. It can be demonstrated, both for the lamprophyres (Reynolds, 1931, pp. 148 and 155) and for the rims, that the calcite was developed at a late stage in the consolidation of the rock, since it replaces the other minerals. However, the rims are usually, as in the analysed example, relatively more heavily charged with calcite than the enclosing lamprophyre and in order to make the analyses more exactly comparable calcite has been subtracted from them, with the results set out in Table II, Nos. 2 and 3.

Table I.

Micro-chemical analysis of a felspathic rim from a quartz xenolith in the Kircubbin dyke, Ards Peninsula (collected from the southern end of the exposed part of the dyke).

	Percentages.	*Molecular Proportions.*
SiO_2	59·57	·9918
Al_2O_3	11·11	·1090
Fe_2O_3	·87	·0055
FeO	·60	·0084
MgO	1·09	·0270
CaO	10·86	·1937
Na_2O	3·78	·0610
K_2O	3·09	·0328
H_2O +	1·10	—
H_2O −	·29	—
CO_2	6·84	·1555
TiO_2	·48	·0060
P_2O_5	tr.	—
S	·14	·0044
MnO	·26	·0037
	100·08	
Less O	·05	
	100·03	

	Norm.	
	Complete.	*Without Calcite.*
Quartz	20·93	24·78
Orthoclase	18·25	21·60
Albite	31·98	37·86
Anorthite	4·23	5·01
Diopside $CaSiO_3$ 2·67 $MgSiO_3$ 2·31	4·98	5·90
Enstatite	·40	·47
Ilmenite	·91	1·08
Magnetite	·90	1·07
Haematite	·25	·30
Pyrite	·26	·31
Calcite	15·55	—
Water	1·39	1·64
	100·03	100·02

Analyst: Edith Kroupa.

Assuming that there was no transfer of magmatic silica, the average composition of the material introduced into the quartz xenolith, for the development of the felspathic rim, has been calculated, and the result is shown in Table II, No. 4. The introduced material is, for convenience, expressed in terms of oxides, but it should be emphasized that there is no evidence that the migrating units were oxides; it is more likely (Holmes, 1936,

p. 417; and Reynolds, 1936, p. 403) that the process involved ionic migration. The data show that the chief materials introduced, apart from the late calcite, were aluminium, sodium, potassium, and calcium. The diffusibilities of the various constituents (expressed as oxides), judged relatively to their concentrations in the vogesite, are as follows, in decreasing order of magnitude from left to right :—

S, K_2O, Na_2O, Al_2O_3, MnO, TiO_2, CaO, H_2O, FeO, MgO, P_2O_5.

As in the Colonsay example of metasomatism of quartzite, potash diffused more readily than soda; alkalies and alumina showed considerably greater power of diffusion than the cafemic materials; and of the latter magnesia was the least diffusible constituent. The fact that the hornblende in the lamprophyre exhibits terminal outgrowths of actinolite and/or tremolite is consistent with loss of alumina and alkalies from the magmatic component (cf. Colonsay, Reynolds, 1936, pp. 378 and 397).

TABLE II.

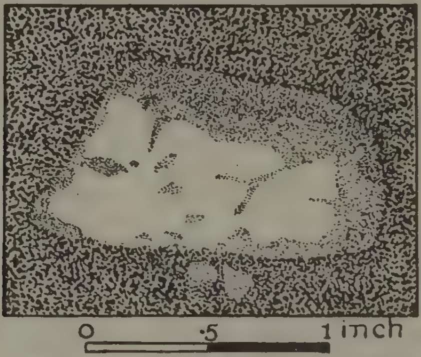
	1.	2.	3.	4.
SiO_2 . .	49·40	50·77	70·45	—
Al_2O_3 . .	12·85	13·21	13·14	44·97
Fe_2O_3 . .	1·98	2·03	1·03	3·52
FeO . .	6·31	6·48	·71	2·43
MgO . .	12·04	12·37	1·29	4·41
CaO . .	7·40	5·94	2·58	8·83
Na_2O . .	2·65	2·72	4·47	15·30
K_2O . .	1·35	1·39	3·65	12·49
H_2O + . .	3·10	3·19	1·30	4·45
H_2O − . .	·20	·21	·34	—
CO_2 . .	1·00	—	—	—
TiO_2 . .	1·10	1·13	·57	1·95
P_2O_5 . .	·24	·25	tr.	tr.
S . . .	tr.	tr.	·17	·58
MnO . .	·31	·32	·31	1·06
	99·93	100·01	100·01	99·99

1. Vogesite (Type B, No. 86). Headland south of Kircubbin. *Analyst*: W. H. Herdsman (Reynolds, 1931, p. 148).
2. No. 1, recalculated without $CaCO_3$.
3. Felspathic rim of quartz xenolith (Table I), recalculated without $CaCO_3$.
4. Composition of material introduced into the quartz xenolith for the development of the felspathic rim.

(*b*) *Evidence from the Newmains Dyke, Dumfriesshire.*

In 1936 Kennedy and Read described a granophyric hornblende-lamprophyre from Newmains, Dumfriesshire, in the following words: " It is a typically heterogeneous, differentiated intrusion and consists of three main rock types associated in an intimate manner. The main rock is a granophyric spessartite or markfieldite, which passes on the one hand into a basic, hornblende-rich type and on the other into a leucocratic variety poor in ferromagnesian constituents" (Kennedy and Read, 1936, p. 118).

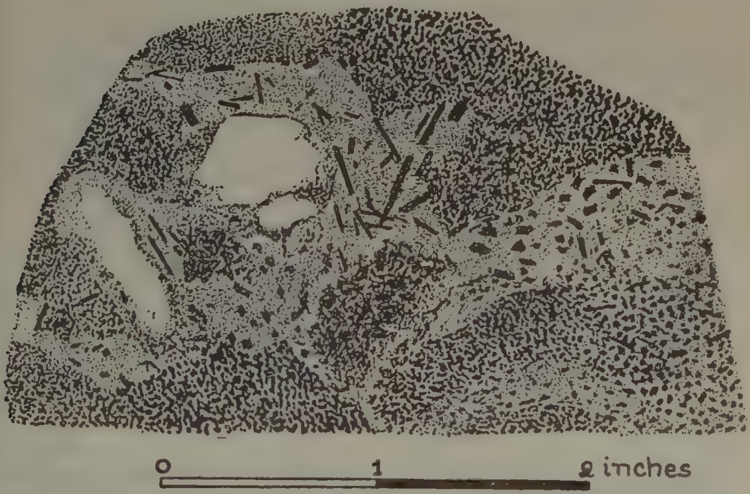
Kennedy and Read regard the heterogeneous character of the dyke as resulting from the differentiation (by "fractional crystallization and filter-pressing effect") of an originally homogeneous magma. In view of the evidence from Colonsay and the Ards lamprophyres, however, the possibility arose that the heterogeneous character of the dyke might have resulted from the metasomatism of sedimentary inclusions. In order to determine whether any evidence of such a process existed, Dr. Holmes and I examined the Newmains dyke from end to end. We found that the dyke contains xenoliths of vein quartz up to about three inches across, and that these xenoliths are rimmed with pink felspathic material. In some instances the quartz xenoliths have narrow pink felspathic rims only (Text-fig. 2). In others, quartz xenoliths with narrow felspathic rims form the centres of patches of markfieldite-pegmatite, coarser in grain and more felspathic than the main body of the dyke. In these patches the subordinate hornblende shows an acicular development (Text-fig. 3). In other instances, again, small felspathic patches contain no visible core of quartz (cf. Colonsay, Reynolds, 1936, pp. 372–3). From the felspathic rims narrow felspathic veins extend through the lamprophyre. A narrow zone of similar felspathic material is, in places, developed along the margin of the dyke, where it is in contact with vein quartz.



Text-fig. 2.—A quartz xenolith (unshaded) with a felspathic replacement-rim (lightly shaded) from which replacement-veinlets extend into the quartz. The specimen was collected from the Newmains dyke; part of this felspathic rim was used for the micro-chemical analysis of Table III.

Although the evidence is considerably less spectacular than that in Colonsay, it is nevertheless, in many instances, abundantly evident that the felspathic material has resulted from the metasomatism of the quartz xenoliths. Further, there is a distinct correlation between the presence of quartz xenoliths and felspathic material; where the dyke is free from such xenoliths it is also free from felspathic patches and schlieren.

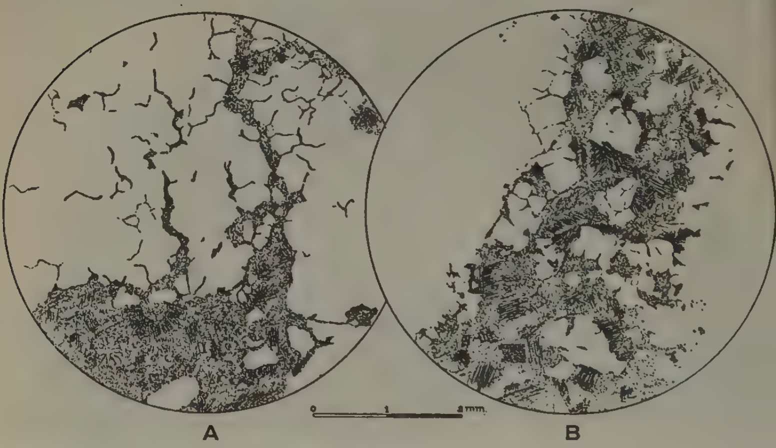
The evidence from the Newmains dyke does not stop here, however. Kennedy and Read have already shown, with the aid of chemical analyses, that the greywacke which margins the dyke is not only hornfelsed, but also considerably enriched in potash, so that it consists largely of potash-felspar. Of the process of enrichment, they say: "As the contact between the igneous rocks and the hornfelses is sharp, it is evident that the transfer must have been effected through the medium of a fluid or gas with great penetrative powers" (1936, p. 123). South-west of Righead farm Dr. Holmes



Text-fig. 3.—Rheomorphic veins of markfieldite-pegmatite (lightly shaded and with indications of acicular crystals of hornblende) developed from the replacement-rims of quartz xenoliths (unshaded) in the Newmains dyke.

and I found lenses of vein quartz, up to two or three inches in length, to be present in the hornfels of the zone of potash enrichment. These quartz lenses, like the quartz xenoliths in the dyke, are margined by zones (in some instances about an inch broad) of pink felspar, from which felspathic replacement lobes occasionally extend into the quartz. The evidence is similar to that of the felspathic rims around quartzite blocks in the breccia which margins the southern intrusion of Port Easdail, Colonsay (Reynolds, 1936, p. 371). It again emphasizes the great mobility of the metasomatizing agents which brought about the felspathization of the quartz; migrating materials were evidently able to proceed beyond the limits of the magma, through solid rock. The evidence also indicates a close relationship between the processes whereby (*a*) the hornfels, which margins the dyke, was enriched in potash, and (*b*) the vein quartz, whether as lenses in the hornfels or as xenoliths in the dyke, was felspathized.

Petrography of the Felspathic Rims.—In thin section the felspathized rims of quartz xenoliths are seen to consist of a granophyric intergrowth of potash-felspar and quartz in which crystals of albite-oligoclase (containing sericite) are embedded. The residual quartz xenoliths are penetrated by replacement-veinlets of felspar and fine granophyre which extend from the rims (Text-fig. 4, B). As in the Colonsay examples, the region of felspathization is seen to have advanced into the xenoliths along the intergranular boundaries; from the forefront of the zone of felspathization finger-like processes of felspar extend along the boundaries of adjacent quartz grains. In places single large quartz grains are partially felspathized, the felspar fingering into the grains along rhombohedral planes.



Text-fig. 4.—A. Replacement-veinlets of granophyre (shaded) extending as an intergranular film from the felspathic replacement-rim into the residual part of a quartz lenticle (unshaded). The specimen was collected south-west of Righead farm from the potash-enriched greywacke which margins the Newmains dyke.

B. A replacement-veinlet of granophyre (shaded) which extends from the felspathic replacement-rim into the residual part of a quartz xenolith (unshaded) collected from the Newmains dyke. The section was cut from the analysed specimen of Text-fig. 2.

The replacement-rims also contain sheaf-like growths of pale yellowish epidote (in some instances clinozoisite). In the advanced stages of replacement, in which the quartz xenolith is almost completely replaced, diopside is present and commonly occurs as aggregates of small crystals.

The felspathic rims of the quartz lenticles collected from the potash-enriched hornfels to the south-west of Righead farm are composed of fine micropegmatite, sometimes spherulitic in its development, with which small euhedral crystals of albite-oligoclase are associated. Replacement-veinlets of granophyre extend from the rim into the quartz as an intergranular film (see Text-fig. 4, A). Euhedral crystals of diopside and a little epidote with a spherulitic development are present in the rims. The rim rock is essentially similar to the leucocratic part of many fine-grained lamprophyres. The hornfels from which the felspathized quartz lenticles were collected is a spinel-cordierite-biotite-hornfels.

Quartz collected from the greywacke, immediately at the southern contact of the dyke, near Meikle Barncleugh, exhibits excellent felspathization phenomena. A granophyric rim has been formed in which abundant small crystals of diopside and needles of apatite are embedded. Replacement-veinlets of felspar extend from the rim into the quartz as a delicate intergranular film (as in Text-fig. 4, A).

TABLE III.

Micro-chemical analysis of a felspathic rim from a quartz xenolith in the Newmains dyke, Dumfriesshire (collected in the second field from the Meikle Barncleugh end of the dyke, at a point about 70 yards from the fence between the second and third fields).

	Percentages.	*Molecular Proportions.*
SiO_2	74·75	1·2446
Al_2O_3	11·25	·1104
Fe_2O_3	·96	·0060
FeO	·47	·0065
MgO	·84	·0208
CaO	2·83	·0505
Na_2O	2·39	·0386
K_2O	4·60	·0488
$H_2O +$	·94	—
$H_2O -$	·12	—
TiO_2	·61	·0076
P_2O_5	·06	·0004
S	·03	·0009
MnO	·26	·0037
	100·11	

Norm.		
Quartz		37·67
Orthoclase		27·16
Albite		20·24
Anorthite		6·40
Diopside	$CaSiO_3$ 2·42 $MgSiO_3$ 2·09	4·51
$CaSiO_3$		·64
Ilmenite		1·15
Magnetite		·49
Haematite		·61
Pyrite		·05
Apatite		·14
Water		1·06
		100·12

Analyst: Edith Kroupa.

Chemistry.—A micro-chemical analysis of a typical felspathic rim from a quartz xenolith collected from the Newmains dyke has been made by Dr. Edith Kroupa, and the results, together with the norm, are shown in Table III. It differs from the micro-chemical analysis of comparable material from the Kircubbin dyke (Table I) in that it shows more potash than soda. In Table IV the analyses of the three rock types from the Newmains dyke—basic markfieldite, markfieldite, and markfieldite-pegmatite—are reproduced from Kennedy and Read's paper for ease of comparison with the new microchemical analysis.

Assuming that there was no transfer of magmatic silica into the quartz xenolith, the average composition of the material that was introduced into the xenolith, for the development of the felspathic rim, has been calculated, the result being set out under 5 in Table IV. As in the Kircubbin example, the introduced material is, for convenience, expressed in terms of oxides. The data show that the chief materials introduced were aluminium, potassium, calcium, and sodium. The diffusibilities of the various constituents (expressed as oxides), judged relatively to their concentration in the markfieldite, were as follows, in decreasing order of magnitude from left to right :

TABLE IV.

	1.	2.	3.	4.	5.
SiO_2	48·00	55·17	58·17	74·75	—
Al_2O_3	10·11	13·90	15·71	11·25	44·57
Fe_2O_3	1·69	1·19	·64	·96	3·80
FeO	6·93	4·39	2·60	·47	1·86
MgO	14·35	8·37	3·82	·84	3·33
CaO	8·90	5·02	5·12	2·83	11·21
Na_2O	3·54	4·53	5·28	2·39	9·47
K_2O	1·10	2·83	4·73	4·60	18·23
$H_2O +$	2·90	2·77	1·53	·94	3·72
$H_2O -$	·13	·20	·16	·12	—
CO_2	·81	0·00	·50	none	none
TiO_2	1·41	1·56	1·63	·61	2·42
P_2O_5	·20	·22	·29	·06	·24
S	n.d.	n.d.	n.d.	·03	·12
MnO	·18	·17	·06	·26	1·03
	100·25	100·32	100·24	100·11	100·00

1. Basic markfieldite, Newmains dyke, Dumfriesshire. *Analyst* : S. Parker (Kennedy and Read, 1936, p. 126).
2. Markfieldite, Newmains dyke. *Analyst* : S. Parker (loc. cit.).
3. Markfieldite-pegmatite, Newmains dyke. *Analyst* : S. Parker (loc. cit.).
4. Felspathic rim of a quartz xenolith from the Newmains dyke. *Microchemical analysis* by Edith Kroupa (Table III).
5. Composition of material introduced into the quartz xenolith for the development of the felspathic rim.

K_2O, MnO, Al_2O_3, CaO, Na_2O, TiO_2, H_2O, P_2O_5, FeO, MgO ;

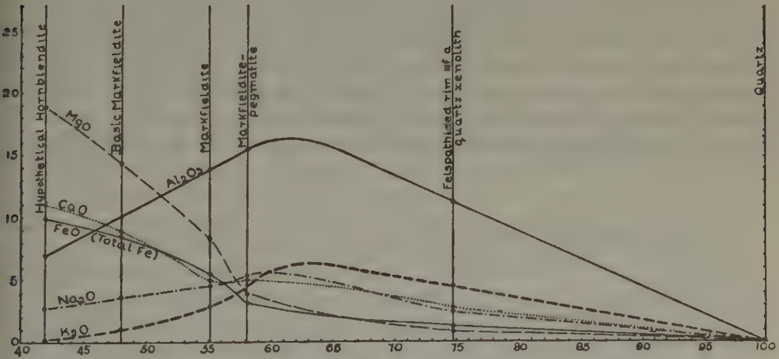
or, judged relatively to their concentration in the basic markfieldite :

K_2O, MnO, Al_2O_3, Na_2O, TiO_2, H_2O, CaO, P_2O_5, FeO, MgO.

The high diffusibility of potash is in keeping with Kennedy and Read's findings that the hornfels which margins the dyke is markedly enriched in potash.

As in the Kircubbin example, alkalies and alumina showed a high power of diffusion, potash diffusing more readily than soda ; lime diffused more readily than iron ; and magnesia was the least diffusible constituent. The fact that the amphibole of the basic markfieldite (and to a smaller extent that of the markfieldite and markfieldite-pegmatite) characteristically exhibits a central core of hornblende and a marginal zone of pargasite (Kennedy and Read, 1936, pp. 125, 127, and 128) is consistent with loss of alumina from the magmatic component of the dyke (cf. Reynolds, 1936, pp. 378 and 397).

The basic markfieldite, markfieldite, and markfieldite-pegmatite of the Newmains dyke are all characterized by the presence of micropegmatite, and by having unzoned albite-oligoclase (Ab_{90}) as their plagioclase. In their discussion as to the petrogenesis of these rock types, Kennedy and Read find difficulty in accounting for a " granophyric late residuum " in these normatively undersaturated rocks, and attempt to account for the micropegmatite by reference to the fact that the albite is to some extent sericitized. They visualize a crystallizing magma from which hornblende, and later plagioclase (more lime-rich than Ab_{90}), were precipitated. At this stage in the hypothetical evolution of the rocks, they say (1936, p. 131) " the residual liquid material reacted with the earlier formed plagioclase which was broken down into albite, epidote, and white mica. This reaction released SiO_2, which crystallized as free quartz in the form of micropegmatite ". In view of the further evidence presented in the present communication, this theoretical explanation of the micropegmatite, with its appeal to the existence of an early plagioclase (for which no evidence is given), becomes unnecessary. From the field and microscopic evidence recorded in the foregoing pages it is apparent that micropegmatite, with associated albite-oligoclase, resulted from the metasomatism of quartz.



TEXT-FIG. 5.—Variation diagram for the rocks from the Newmains dyke, Dumfriesshire.

As already noted, quartz xenoliths with narrow felspathic rims (micropegmatite and albite) sometimes form the centre of patches of markfieldite - pegmatite. Quartz — micropegmatite — markfieldite - pegmatite—markfieldite—basic markfieldite clearly form a series, the variation diagram of which is shown in Text-fig. 5. The variation diagram is closely similar to that representing the Colonsay series: quartzite—syenite—appinite—hornblendite (Reynolds, 1936, p. 396), in which syenite and appinite have demonstrably resulted from the metasomatism of quartzite by alk-aluminous and cafemic emanations which passed successively from or through hornblendite magma. It is significant that the curves for the various constituents in Text-fig. 5, when prolonged at the basic end, pass at approximately 42 per cent silica through the composition of hornblendite (see Table VI, No. 1). The series: basic markfieldite—markfieldite—markfieldite-pegmatite can be expressed in terms of sialic quartz, alk-aluminous emanations, and cafemic materials.

It can hardly be imagined that the processes of metasomatism and rheomorphism were restricted to the alteration of vein quartz. Indeed, Kennedy and Read have already shown that in some places, where markfieldite-pegmatite occurs at the margin of the dyke, there is gradation from markfieldite-pegmatite through a transition zone to the hornfels. They describe the transition zone as follows (1936, pp. 132–3): "It consists of a mixture of igneous and sedimentary material so intimate that it is often impossible to tell whether it represents a contaminated igneous mass or a highly altered sediment. . . . Euhedral crystals of hornblende are present even in obvious sedimentary xenoliths and must represent porphyroblastic growths."

(c) *Comparable Evidence from other Lamprophyre Dykes.*

Evidence, such as has been presented in the preceding pages, concerning the development of felspathic material by the metasomatism of xenoliths in lamprophyre dykes is by no means new. Abundant evidence of such a process has already been furnished both by H. G. Smith and by Flett.

H. G. Smith has described quartz xenoliths with felspathic rims from Cornish lamprophyres (1929) and from lamprophyres near Sedbergh (1930). Of one such xenolith in a Cornish biotite-lamprophyre (1929, p 264) he writes: "Forming an irregular belt between the quartz and the lamprophyre is a quantity of much-decomposed felspar, and this graduates into the lamprophyre, the felspar (untwinned) becoming clearer and separating into distinct crystals without marked elongation; then the biotite appears and the rock becomes normal."

In descriptions of various xenoliths Smith records evidence from which it can be inferred that the felspar, associated with the xenolithic quartz, has arisen as a replacement of the latter. Such evidence includes descriptions of the development of intergranular films of felspar between the individual quartz grains of the xenoliths in two of the Cornish lamprophyres. Thus, in one xenolith, from a biotite-lamprophyre (Smith, 1929, p. 263), the quartz is traversed by a network of clear threads of felspar which follow the boundaries of individual quartz grains. A more advanced stage of the development of felspar is described by Smith (1929, p. 265) as follows: "In one case, more or less separated pieces of quartz are embedded in felspar and give a very strong suggestion that they are residual, much of the mineral having been (apparently) converted into the felspar. This idea is considered to be supported by the existence of some curious streaks traversing the quartz."

Flett (1929) has described felspathized schist xenoliths from a vogesite dyke outcropping on the western side of Loch Lomond, about one mile south of Inverbeg. The dyke contains numerous xenoliths and xenocrysts. Amongst the former are fragments both of the local schist and of garnetiferous schist, the latter having evidently been transported upwards from a lower level. Of particular interest in the present connection is the fact that many of the schist xenoliths have borders of varying width of coarsely crystalline felspar. Further, the dyke contains inclusions of vogesite similar to, but coarser in grain than, the main dyke rock. Flett draws special attention to the igneous appearance of these inclusions but shows that the evidence indicates that they result from the alteration of schist fragments, since some of them contain central patches of schist. Flett's interpretation of the patches of coarse-grained vogesite is that they "seem to have arisen from the felspathization of a schist fragment, permeated by the magma of the rock".

The patches of coarse-grained vogesite in the Inverbeg lamprophyre are therefore closely allied to the patches of appinite in the Colonsay hornblendite which have resulted from the metasomatism of quartzite xenoliths.

Recently Anderson and Tyrrell (1936) have traced the continuation of the Inverbeg lamprophyre on the eastern side of Loch Lomond, where it appears about a mile south-south-east of Rowardennan. They are not in sympathy with Flett's interpretation of the vogesite patches, but they do not, however, record any evidence that is adverse to such an interpretation. Moreover, they themselves record felspathized xenoliths of vein quartz and schist (1936, p. 379).

Anderson and Tyrrell also describe a sheet of lamprophyre at Inversnaid, the upper two feet of which, against the schist roof, is a fine-grained pink felspathic rock. The lower part of the sheet is packed with xenoliths of local schists, phyllites, vein quartz, and quartz-chlorite vein rock. Of these xenoliths they write: "All these types provide excellent illustrations of permeation by felspar derived from the enclosing igneous rock" (1936, p. 382). Moreover, the rock itself is found, in thin section, to contain quartz xenoliths, "with a reaction rim of turbid pink felspar" (1936, p. 378). The evidence is clearly the same as that presented in the present communication and, in the absence of chemical analyses, the expression "permeated by felspar" may be interpreted as indicating that at least alkalies have been introduced into the xenoliths. It is unlikely, in view of the existing chemical data for other occurrences, that felspar was introduced as such.

3. THE PETROGENESIS OF THE CALEDONIAN LAMPROPHYRE SUITE.

The British Caledonian dyke suite includes such rock types as biotite-peridotite; hornblende-peridotite; biotite- and hornblende-lamprophyres (either of which may contain augite); malchite; markfieldite; porphyrite; felspathic types including varieties described as felsite, orthophyre, orthoclase-porphyry, albitophyre, and albite-porphyry; and, finally, quartz-porphyry. The Caledonian lamprophyres clearly form part of a series which ranges in composition from ultrabasic to syenitic or granitic. Any hypothesis that attempts to account for the origin of the lamprophyres must, therefore, if it is to be successful, be equally applicable to the associated rock types.

In 1931 (pp. 159–163) I attempted to account, in terms of crystal differentiation, for the association of hornblende- and biotite-pyroxene-lamprophyres, porphyrites, and alkali-felspar-porphyries in the Caledonian dyke swarm of the Ards Peninsula. The dykes in question form a conjugate series in which the felspathic and hornblendic types appear to have been emplaced before the biotite-pyroxene varieties. Their respective magmas, already charged with crystals, were therefore regarded as having been derived from a stratified magma reservoir in which the potential felspathic and hornblendic types overlay the potential biotite-pyroxene varieties.

Hornblende was visualized as sinking from a crystallizing " granite " magma into a lower horizon of basaltic composition. The partial resorption of the hornblende, with the concomitant precipitation of phases with which the basaltic magma was saturated (Bowen, 1928, p. 270), together with crystal sinking, was suggested as a mechanism whereby a composition-layering might be developed. There is, however, no evidence in the district which amounts to proof of such a hypothesis, and this speculative suggestion is now abandoned in the face of further evidence.

It has been shown in the preceding pages that individual heterogeneous members of the Ards swarm, as exemplified by the Kircubbin dyke, show variation from melanocratic lamprophyre to felspathic types of syenitic and granitic composition. Moreover, the rock types in the Kircubbin dyke, like those of the Newmains dyke (which is a member of what is probably the Scottish continuation of the Ards dyke swarm), can be adequately expressed in terms of sialic material, alk-aluminous emanations, and ultrabasic cafemic material. Further, it is clear, from the recorded evidence of the felspathization of sialic material in both hornblende- and biotite-lamprophyres, that alk-aluminous emanations are characteristically associated with the magmatic antecedents of hornblende- and biotite-lamprophyres alike. The use of the term " lamprophyre magma " is deliberately avoided.

As evidenced by the Kircubbin and Newmains dykes, veins may proceed through the lamprophyre from the felspathic patches and schlieren which resulted from the addition of alk-aluminous emanations to sialic material. Such veins bear witness that the felspathic patches and schlieren may eventually become magmatic or rheomorphic; presumably this is accomplished when the introduction of alk-aluminous emanations is accompanied by a sufficient inflow of energy (see Holmes, 1936–7, p. 253; and 1937, p. 216, for a scheme of magma development). The possibility now naturally arises that these processes, so well exemplified by the phenomena in individual dykes, may be small-scale replicas of the main process which was active in the generation of the rock types associated together in the various Caledonian dyke swarms. The similarity between these rock types and those found in the individual heterogeneous dykes will already be apparent.

TABLE V.

Analysis of alkali-felspar-porphyry, from a dyke occurring south of Cloghy, Ards Peninsula.

	Percentages.	*Molecular Proportions.*
SiO_2	60·78	1·0120
Al_2O_3	17·94	·1760
Fe_2O_3	·84	·0053
FeO	2·65	·0369
MgO	1·77	·0439
CaO	3·16	·0564
Na_2O	5·44	·0878
K_2O	2·17	·0230
H_2O+	2·25	—
H_2O-	·40	—
CO_2	1·72	·0391
TiO_2	·28	·0035
P_2O_5	·32	·0023
MnO	·09	·0013
	99·81	

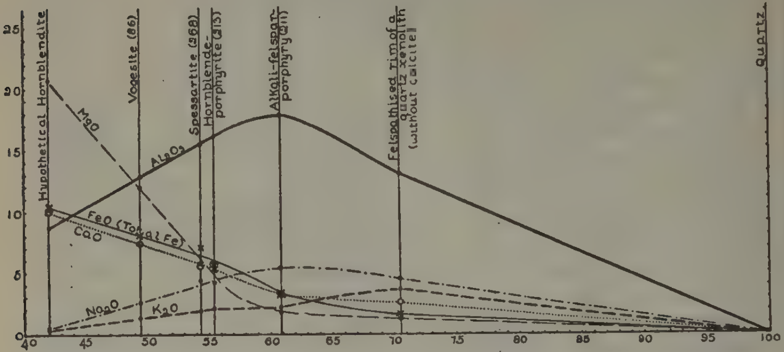
Norm.		
Quartz		15·20
Orthoclase		12·80
Albite		46·03
Anorthite		2·89
Corundum		5·59
Hypersthene	$MgSiO_3$ 4·40 $FeSiO_3$ 3·87	8·27
Ilmenite		·53
Magnetite		1·23
Apatite		·77
Calcite		3·91
Water		2·65
		99·87

Analyst: W. H. Herdsman.

When the Ards dykes were described in 1931, no analysis of alkali-felspar-porphyry, the most leucocratic member of the swarm, had been made. For the sake of completion, the alkali-felspar-porphyry (No. 211), described as occurring south of Cloghy (1931, pp. 106 and 151), has now been analysed. The rock consists essentially of phenocrysts and glomeroporphyritic groups of potash-felspar and albite embedded in a felspathic matrix. The matrix consists of euhedral or subhedral crystals of albite and potash-felspar with a small amount of finely crystalline interstitial material composed of felspar and quartz. The felspars are flecked with sericite. Although the rock is essentially felspathic, chlorite is present, characteristically as small flakes, and there is a little calcite and accessory pyrite and apatite. The rock contains small xenoliths of greywacke, the marginal parts of which have been strongly felspathized, so that alkali-felspar and associated chlorite form an intergranular matrix for the residual quartz of the greywacke.

The analysis is shown, together with the norm, in Table V. As is characteristic for the hornblende-lamprophyres of the district, and for the felspathic rims of the quartz xenoliths, the alkali-felspar-porphyry contains more soda than potash.

In Text-fig. 6 a variation diagram for the series: hornblende-lamprophyre—alkali-felspar-porphyry has been constructed. When the composition of the analysed felspathic rim from a quartz xenolith in the Kircubbin dyke (Table II, No. 3) is added to the right-hand end of the diagram, the curves can be extended in this direction so as to pass quite naturally through these points towards quartz. The vogesite from which the analysed xenolith was obtained is of the most basic type (represented by vogesite, No. 86, Table II, No. 1) plotted on the diagram, and the related rocks of the district fall on curves connecting the points representing the composition of this rock type with those representing the composition of the metasomatic felspathic rim of the quartz xenolith (cf. the variation diagram for the Newmains dyke, Text-fig. 5).



Text-fig. 6.—Variation diagram for the rocks of the Caledonian dyke-swarm of the Ards Peninsula, Co. Down.

Further, it is significant that, when extended towards the basic end, the curves pass through the composition of hornblendite. The composition indicated by the curves at a silica percentage of 42 is shown in Table VI, under 2, and the principal constituents of the Colonsay hornblendite are given for comparison under 3; there is seen to be a close similarity.

When the associated biotite-pyroxene-lamprophyres are added to the diagram, they fall at the basic end, and their points are somewhat scattered. If, however, the curves are drawn through these points so as to represent the average variation, then, when extended towards the basic end, they pass at 42 per cent of silica through a composition that is closely similar to that of the Caledonian biotite-pyroxenite at the eastern end of the Newry Complex; compare also Nos. 4 and 5 in Table VI.

Table VI.

	1.	2.	3.	4.	5.
SiO_2 .	42·0	42·0	42·54	41·71	42·0
Al_2O_3 .	7·0	8·8	9·00	8·55	9·4
FeO* .	9·7	10·2	9·46	12·05	9·1
MgO .	19·0	21·0	19·41	14·65	14·9
CaO .	11·0	10·1	10·82	11·74	10·1
Na_2O .	2·6	·5	·53	·60	·6
K_2O .	·1	·4	·33	3·65	3·5

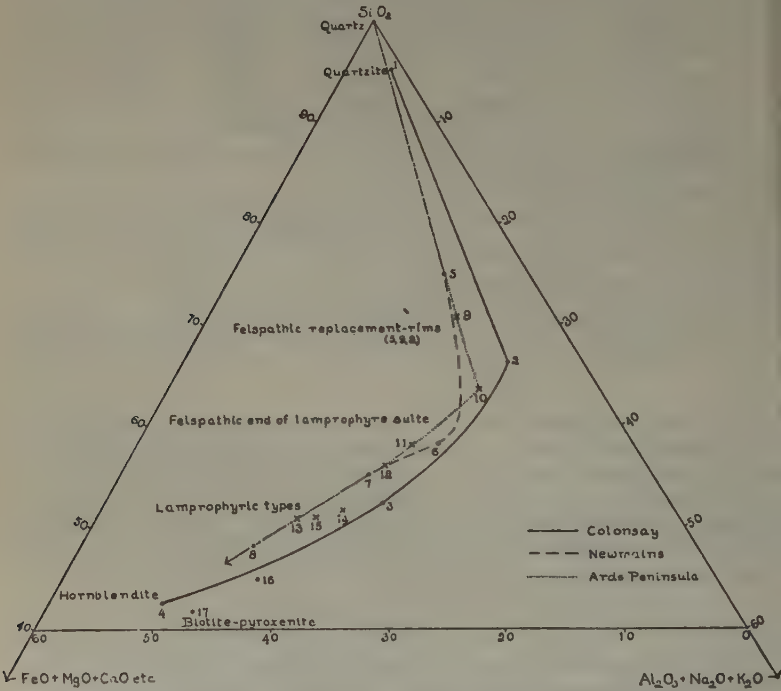
*Total iron oxides expressed as FeO.

1. Hypothetical ultrabasic end (hornblendite) of Newmains dyke. Graphically determined for $SiO_2 = 42$ per cent.
2. Hypothetical ultrabasic end of the hornblende-lamprophyre dyke suite of the Ards Peninsula. Graphically determined for $SiO_2 = 42$ per cent.
3. Hornblendite, Colonsay. For complete analysis by L. S. Theobald, see Reynolds, 1936, p. 394, Table ii, No. 1.
4. Biotite-pyroxenite, eastern end of Newry Complex. For complete analysis by L. S. Theobald, see Reynolds, 1934, p. 608.
5. Hypothetical ultrabasic end (biotite-pyroxenite) of the biotite-pyroxene-lamprophyre suite of the Ards Peninsula. Graphically determined for $SiO_2 = 42$ per cent.

The various members of the Ards dyke swarm can be expressed in terms of sialic quartz, alk-aluminous emanations, and ultrabasic cafemic materials, the latter being directly related to hornblendite or biotite-pyroxenite. The common association of, and gradation between, biotite-pyroxenite and hornblendite (Reynolds, 1935, p. 455) is reflected in the association of biotite-pyroxene- and hornblende-lamprophyres.

The close similarity between the Ards dyke suite: vogesite—porphyrite—porphyry, and the rock series characterizing individual heterogeneous intrusions of Caledonian age is evident from the triangular diagram, Text-fig. 7. The heavy line represents the Colonsay series: quartzite—syenite—appinite—hornblendite, in which the syenite and the appinite are successive stages in the metasomatism of quartzite xenoliths. The sharp bend in the line (at syenite) indicates the progressive way in which the quartzite xenoliths were transformed to rocks of igneous composition, the process having involved introduction into the xenoliths of alkalies and alumina, followed by cafemic constituents (Reynolds, 1936). The appinites are coarse-grained representatives of the vogesite—spessartite series (Bailey, 1916, pp. 167–8), so that the Colonsay series is directly comparable with the finer-grained hornblende-lamprophyre—porphyrite—porphyry series.

The dashed line represents the series: quartz—micropegmatite—markfieldite-pegmatite—markfieldite—basic markfieldite of the heterogeneous Newmains dyke, in which the markfieldite is a granophyric spessartite. It is clear from the field evidence already described that the micropegmatite and markfieldite-pegmatite are successive stages in the metasomatism of xenoliths of vein quartz (see Text-fig. 3). The triangular diagram makes it clear (*a*) that for the development of the micropegmatite, alkalies, and alumina, together with a small proportion of cafemic materials, were



Text-fig. 7.—Triangular diagram to illustrate petrogenetic relationships of lamprophyres.

1. Quartzite xenolith from the Colonsay hornblendite (Reynolds, 1936, p. 394).
2. Syenite rim from a quartzite xenolith in the Colonsay hornblendite (loc. cit.).
3. Appinite rim from a quartzite xenolith in the Colonsay hornblendite (loc. cit.).
4. Hornblendite, Colonsay (loc. cit.).
5. Felspathic rim from a quartz xenolith in the Newmains dyke, Dumfriesshire. This paper, Table III.
6. Markfieldite-pegmatite, Newmains dyke (Kennedy and Read, 1936, p. 126).
7. Markfieldite, Newmains dyke (loc. cit.).
8. Basic markfieldite, Newmains dyke (loc. cit.).

introduced into the quartz ; (*b*) that the development of markfieldite-pegmatite involved introduction of a higher proportion of cafemic oxides relative to alkalies and alumina ; and (*c*) that the markfieldite and basic markfieldite can be expressed in terms of hornblendite (similar to that of Colonsay) and markfieldite-pegmatite, the latter representing quartz and alk-aluminous emanations. In other words, the basic markfieldite and markfieldite can be expressed in terms of hornblendite (or cafemic emanations), alk-aluminous emanations, and sialic quartz. The line of variation for the Newmains series is similar to, though not identical with, that for the Colonsay series.

The dotted line represents the variation shown by the hornblende-lamprophyre—porphyrite—porphyry series of the Ards dyke swarm. The most basic member plotted (point 13) represents vogesite of the type from which the analysed metasomatic felspathic rim of a quartzite xenolith was collected ; point 9 represents the analysis of this rim. The other members of the series fall on a curved line connecting these points ; this line, with its sharp bend, clearly resembles those which represent the Colonsay and Newmains series. As in these latter cases, the various members of the Ards hornblende-lamprophyre—porphyrite—porphyry series can be expressed in terms of hornblendite (or cafemic emanations), similar to the Colonsay hornblendite, alk-aluminous emanations, and sialic quartz. The alkali-felspar-porphyry, like the metasomatic felspathic rim, can be expressed as sialic quartz, or quartz-rich material, into which alkalies and alumina, together with a small proportion of cafemic oxides, have been introduced. The porphyrites and vogesites may represent either the further introduction of cafemic constituents or syntexis of hornblendite magma and alkali-enriched sialic material.

The two analyses of biotite-pyroxene-lamprophyres from the Ards swarm are represented by points 14 and 15, whilst point 16 represents a Caledonian biotite-pyroxene-lamprophyre from Sutherland (Read, 1926, pp. 169–170). Lack of analyses makes it impossible

*9. Felspathic rim from a quartz xenolith in the Kircubbin dyke, Ards Peninsula, Co. Down. This paper, Table I.

*10. Alkali-felspar-porphyry, Ards Peninsula, Co. Down. This paper, Table V.

*11. Hornblende-porphyrite, Ards Peninsula, Co. Down (Reynolds, 1931, p. 109).

*12. Spessartite, Ards Peninsula, Co. Down (loc. cit, p. 151).

*13. Vogesite, Ards Peninsula, Co. Down (loc. cit., p. 148).

*14. Pyroxene-minette, Ards Peninsula, Co. Down (loc. cit., p. 156, No. 276).

*15. Pyroxene-minette, Ards Peninsula, Co. Down (loc. cit., p. 156, No. 47).

16. Augite-minette, Sutherlandshire (Read, 1926, pp. 169–170).

17. Biotite-pyroxenite, eastern end of the Newry Complex, Co. Down (Reynolds, 1934, p. 608).

* Analyses recalculated without calcite.

to draw a line of variation for this group, but from the location of the points representing the three analysed biotite-pyroxene-lamprophyres they appear to be related to biotite-pyroxenite similar to that of Caledonian age in the Newry Complex (point 17).

No other analyses of uncrushed British Caledonian lamprophyres appear to have been recorded, and there are only about six other analyses of the felspathic end of the series. It is therefore impossible at present to apply a further chemical test to the hypothesis. However, from the records of associations of lamprophyres, porphyrites, and porphyries, the serial relationship appears to be a general one. Thus, Bailey (1916, pp. 173–8) has recorded an association of lamprophyres, malchites, porphyrites, porphyries, and felsites in the Ben Nevis and Glen Coe area, in which various characteristics relate the successive members of the series. The felsites, which have a micrographic texture, are related to the porphyries by the presence, in some instances, of phenocrysts of alkali-felspar. In a few cases transitions between the porphyries and porphyrites are provided by the presence of quartz and orthoclase amongst the phenocrysts of the porphyrites. Then instances in which the porphyrites " combine the structures of the porphyrites and the lamprophyres, with two generations of felspar, hornblende, and biotite, all markedly idiomorphic " (Bailey, 1916, pp. 174–5) are recorded. Some of the porphyrites are said to show " strong malchitic affinity " in their structure (Bailey, 1916, p. 175). Finally, several of the malchites, which are richer in hornblende than usual, " serve as a transition to the spessartites."

In Perthshire Flett (1905, pp. 114–131) records an association of lamprophyres, porphyrites, and porphyries (quartz-porphyries and orthoclase-porphyry). Of these Flett writes : " Many transitions can also be shown to exist between the various groups, and in some cases it is a matter of difficulty to decide in which class an individual specimen is to be placed. There can, consequently, be no doubt that they all belong to the same great series of intrusions " (p. 115).

Again, from the Morvern and Moidart area, A. G. MacGregor and Kennedy (1932, pp. 106–107) record a younger suite of intrusions which form sheets and subordinate dykes of " fine-grained, often foliated, hornblende-lamprophyres together with coarser-grained (sometimes very coarse), ultrabasic, basic, and acid types ", whilst from Kirkcudbrightshire B. C. King (1937) records an association of lamprophyres, diorite-porphyrites, albite-porphyries, and albitophyres.

It only remains to recapitulate the evidence for the ultrabasic end of the lamprophyre—porphyrite—porphyry series. In two instances an association of ultrabasic rock, of the composition of biotite-pyroxenite or hornblendite, with lamprophyre has been found in one and the same intrusion. In Glen Orchy, Kynaston (1908, pp. 91–5) found that a sheet-like mass of kentallenite passes, in its lower part, to picrite (a hornblende-rich biotite-pyroxenite, Reynolds, 1934, p. 464), which exhibits a marginal modification "resembling basic lamprophyre" against the country rock. The marginal rock—a hornblende-lamprophyre which contains augite, pseudomorphs after olivine, and some biotite—exhibits "vein-like streaks and patches rich in felspar". The felspar-rich patches are "somewhat coarser than the surrounding rock, but graduate imperceptibly into it. They consist of idiomorphic plagioclase and micropegmatite. The lower margin of the picrite thus represents a peculiar modification of more acid composition, allied to the lamprophyres" (Kynaston, 1908, p. 93).

Similarly the Colonsay hornblendite, to the north of Port Easdail, exhibits a lamprophyric margin against the phyllite. This occurrence is described by Wright as follows (1911, p. 30): "A peculiar lamprophyric phase of the marginal portions of the mass occurs on the rocks north of Port Easdail, and is best described as a quartz-bearing vogesite. It is medium-grained, and, in its most typical form, consists of lath-shaped hornblendes embedded in a pink felspathic matrix."

In addition to the field association of dykes and sheets of lamprophyre and ultrabasic rock already mentioned as recorded by A. G. MacGregor and Kennedy, two other such associations are to be noted. In Perthshire (Flett, 1905, pp. 125–131) a small number of dykes of ultrabasic rock are associated with the lamprophyre dykes of Carn Dearg type. The lamprophyres are mostly vogesites, but a minette is also recorded. Two main types of ultrabasic dyke rock have been distinguished: hornblende-peridotite and biotite-peridotite. With regard to the relationship of the peridotites to the lamprophyres, Flett writes (1905, p. 31): "These peridotites are supposed to be genetically allied to the Carn Dearg lamprophyres not only because they occur in the midst of the area occupied by these dykes and have the same geological relationships, but also because the minerals of which they consist have precisely the same characters and have decomposed in the same way." Both from the descriptions and from the photomicrographs (op. cit., plate vii, fig. 6) the hornblende-peridotite appears to be closely allied to the hornblendite of Colonsay.

In Ross-shire (Flett, Hinxman, and others, 1912, pp. 115–129) intrusions of peridotite and scyelite are found associated with dykes of lamprophyre (augite-minettes) and lamproschist. Of the ultrabasic intrusion, described as mica-hornblende-schist, Flett remarks that the great abundance of mafic minerals "shows that this was probably a peridotite, of the same magmatic succession as the lamprophyres". Of particular interest in the present connection, and worthy of further investigation, are the following two occurrences:—

(*a*) At one locality scyelite contains rounded masses of appinite (op. cit., pp. 115 and 128–9). The latter are coarsely granitic or pegmatitic in texture and are often speared by long crystals of hornblende. Of the inclusions Flett remarks that the "abundance of ferromagnesian minerals in a mesostasis rich in silica and alkalies is a feature which recalls the lamprophyres ". Moreover, the description suggests the possibility of a relationship like that in Colonsay, where inclusions of appinite in hornblendite have resulted from the metasomatic replacement of quartzite (Reynolds, 1936).

(*b*) Another intrusion of scyelite passes to garnetiferous quartz-mica-syenite at the northern end of the intrusion (op. cit., p. 115). It is recorded by Hinxman that the syenite is " unique in containing garnet and muscovite ". Hinxman writes : " It has been suggested by Dr. Flett that the abnormal characters of the quartz-mica-syenite referred to above may be due to the absorption by the igneous rock of a certain quantity of the sediments into which it is intruded." It would be interesting to know whether a re-investigation, in the light of recent knowledge, would not show that the garnetiferous quartz-mica-syenite is a product of metasomatism of the pelitic gneiss (which at the contact is already converted to a garnetiferous hornfels) by materials which migrated from or through the scyelite.

4. Summary of Conclusions.

The present investigation establishes the following facts :—

(1) Xenoliths of vein quartz in a vogesite dyke near Kircubbin, Ards Peninsula, Co. Down, exhibit felspathic replacement-rims.

(2) The replacement-rims have developed as a result of the introduction of alk-aluminous emanations, and to a smaller extent of cafemic constituents, into the quartz xenoliths.

(3) Rheomorphic leucocratic veins extend from the felspathized rims through the lamprophyre, the veins being essentially similar in type to felspathic dykes which are associated with British Caledonian lamprophyres.

(4) Phenomena similar to those of (1), (2), and (3) are developed in the Newmains dyke, Dumfriesshire.

(5) Quartz lenticles in potash-enriched hornfels in the vicinity of the Newmains dyke exhibit similar replacement-rims, and thus bear witness to the high degree of mobility of the emanations which brought about the felspathization.

(6) Felspathization of xenoliths is shown, by reference to various recorded examples, to be a phenomenon which characterizes British Caledonian lamprophyres.

(7) The Caledonian dyke suite : lamprophyre—porphyrite—porphyry is shown to parallel the rock suites developed by processes of metasomatism and rheomorphism in individual heterogeneous intrusions.

(8) Ultrabasic types, such as hornblende-peridotite, biotite-peridotite, hornblendite, biotite-pyroxenite, and scyelite, are shown to be the most basic members of the lamprophyre suite.

(9) Chemically, the various components (*a*) of single heterogeneous lamprophyre dykes and (*b*) of the Caledonian dyke suite as a whole are shown to be expressible in terms of sialic material, alk-aluminous emanations, and cafemic emanations, the latter being directly related to the ultrabasic types listed in (8).

In view of these facts, it is suggested that processes of metasomatism and rheomorphism have played a leading part in the evolution of the British Caledonian lamprophyre suite.

In conclusion I gratefully acknowledge a grant from the Government Grant Committee of the Royal Society, out of which the cost of the micro-chemical analyses has been defrayed.

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Cummingtonite-bearing Rocks from the Lewisian.

By C. E. Tilley.

MANGANIFEROUS schists carrying cummingtonite or grunerite are now known from several areas of the Lewisian of Scotland. Cummingtonite in paragneisses was first described from the Gairloch area (1)[1] and it has since been met with at two localities in the Lewisian inlier of Glenelg—at Druideag Lodge, Loch Duich (2), in association with eulysites, and in the gorge of Glen Beag, 5½ miles south of this point—here associated with rhodonite and pyroxmangite (3).

The original locality of Loch Bad an Sgalaig in the Gairloch area contains petrographic types so far unrepresented in the Glenelg region, and a closer study of these assemblages is of interest as they appear to throw light on the original character of the sediments from which both the cummingtonite rocks and the eulysites of Glenelg have been derived.

The Gairloch occurrence is described by Clough as follows :—

"On the south-west side of a mica schist, about 700 yards south-west of the outlet of Loch Bad an Sgalaig in the Gairloch area, a rock which strikes north-west consists mainly of subparallel white threads of a fibrous hornblende (cummingtonite) enclosing small garnets. The band is several yards wide but cannot be traced far. A bulk analysis of it gives as much as 7 per cent of manganese oxide and the analyses of the two chief minerals—the garnet (spessartite) and the cummingtonite—show manganese oxide in both. The rock may perhaps be regarded as an altered manganiferous sediment "(1), p. 238.

This cummingtonite-garnet-schist, which is traceable 20–30 yards, is flanked on its south-west side by a green-weathering hornblende-schist. About 200 yards north-west of this exposure another outcrop of a cummingtonite-schist is developed. When the exposures are examined in detail a variety of petrographic types is found—all of which, from the manner of their weathering with a black crust, contain a significant content of manganese. The rock types may be subdivided as follows :—

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[1] The numbers in parentheses refer to References at end of article.

1. Cummingtonite-garnet-schist ± quartz.
2. Cummingtonite-garnet-sideroplesite-ankerite-schist.
3. Banded quartz-knebelite-magnetite-schists with accessory garnet and cummingtonite (eulysitic facies).

The first rock type—with analytical data on the rock and its constituent minerals—has been fully described in the *Survey Memoir* (1), pp. 83–4. The silky white fibrous cummingtonite of this quartz-bearing type is optically positive and has γ 1·660 (cf. Table I, cols. 3, 4, 5).

Cummingtonite-garnet-sideroplesite-ankerite-schist.

In these rocks carbonates form essential constituents and quartz is absent. They weather characteristically with a black crust. Cummingtonite forms colourless prisms intimately twinned on (100) and reaching 1·5–2 mm. in length. The optic axail angle is high and the crystals are negative, $\gamma = 1{\cdot}694$.

Garnet forms idioblastic dodecahedra averaging 0·5 mm. in diameter. Both cummingtonite and garnet contain inclusions of magnetite and fine-grained carbonate.

In the latter the dark inclusions and in some examples the carbonates form a regularly arranged pattern rendered familiar by the examples of the manganese garnets of Bastogne (dodecahedral arrangement).

The carbonate constituents of the rocks occur, however, not only as inclusions but also in pockets and lenses between the remaining minerals. In these they form polygonal grains sometimes with dark edges due to oxidation of ferrous carbonate. Immersion liquids show that two varieties of carbonate are present, (1) sideroplesite, (2) ankerite.

The first, more abundant, has ω close to 1·845 and is a member of the magnesite-chalybite series, corresponding to a solid solution rich in the chalybite member (80 per cent $(FeMn)CO_3$). Ankerite, with which it is intergrown, and which sometimes forms brown films on fractured surfaces of the rocks, has ω varying between 1·740 and 1·750. The presence of this member is also indicated by the occasional glide planes on f $(02\bar{2}1)$ and by microchemical reactions for lime. Ankerite of this refraction contains 70 per cent or more of $CaCO_3.(FeMn)CO_3$.

An analysis of this rock type is given below (Table I, col. 1), its mineral composition corresponding approximately to : Cummingtonite, 40 per cent, garnet, 18 per cent, sideroplesite, 22·5 per cent, ankerite, 17·5 per cent, iron ores, 2 per cent.

The third type of rock is characteristically banded, built up of grey bands of fine textured quartz $\frac{1}{2}$ inch thick and iron ore layers ($\frac{1}{8}$–$\frac{1}{4}$ inch).

In slices these rocks are seen to consist of :—

1. Ore bands—essentially of magnetite and knebelite of composition Fe : Mn approximately 1 : 1, with accessory garnet rich in

magnetite inclusions and slender prisms of cummingtonite. Near the edges of these bands the olivine is found in direct contact with quartz. An analysis of an iron ore band of this type is given in Table I, col. 2. This rock has the composition, magnetite, 28 per cent, knebelite, 20 per cent, quartz and accessory garnet and cummingtonite.

2. Quartz bands, dominantly of fine texture, the quartz often with a preferred orientation. Within this quartz aggregate may occur grains of knebelite, accessory garnet and cummingtonite.

The knebelite of the bands is frequently stained reddish with iron oxide and in the quartzose layers is sometimes found intimately associated with fine-grained carbonate and a cleaved colourless silicate in such a way as to suggest that both have developed subsequently, the silicate partly at the expense of the olivine. The carbonate of these patches is readily destroyed by weak cold HCl. This property and the presence of twinning on $(01\bar{1}2)$ indicate it as calcite.

Both it and the knebelite are removed by weak HCl, leaving the associated silicate unattacked. The properties of this mineral are difficult to determine owing to its confused crystallization but the following characteristics have been determined on an uncovered slice of the rock: β 1·735, oblique extinction from a predominant cleavage, and optic sign positive. These properties are in agreement with an iron-rhodonite but this identification cannot be conclusively proved with the material available. As indicated above both calcite and silicate appear to be derived at the expense of the olivine, subsequent to its crystallization and with introduction of lime.

The carbonate minerals of this suite of rocks provide the clue to the origin of the rocks themselves. Both knebelite and cummingtonite are doubtless derived from a reaction between sideroplesite and quartz, the former being in excess in the carbonate types, the latter in the quartzose knebelite and cummingtonite types.

It is of interest to note that the cummingtonite-garnet-schists, with little or no quartz and devoid of interstitial carbonate, often contain fine carbonate inclusions in the garnet as in the carbonate-rich varieties, indicating that before all carbonate was used up in the formation of cummingtonite some of it became entangled in the growing garnets.

The reason for the development of olivine in certain bands, and cummingtonite to the exclusion of olivine in others, would require systematic analyses of a group of minerals of the several bands. It may be noted, however, that the olivine bands are much richer in ferrous + manganous oxide relative to magnesia (after subtraction of FeO for magnetite) than the amphibole-bearing bands. While amphibole development may be favoured under lower temperature conditions than that of olivine, it may well be, in the examples now referred to, that this compositional difference is responsible under similar physical conditions for the appearance of olivine in the iron-manganese-rich environment.

In this connection the partition of the oxides of Fe, Mn, and Mg in the garnet and cummingtonite of the rock analysed by J. S. G. Wilson (Table I, cols. 4 and 5) is of interest. Iron and manganese are concentrated in the garnet, which contains insignificant quantities of the pyrope molecule, while the cummingtonite contains almost the whole of the magnesia and relatively little of MnO.

A similar partition of Fe and Mg between garnet and cummingtonite and gedrite has been noted by Eskola and Kervinen in a cummingtonite-amphibolite from Isopää, Kalvola, Finland (4), p. 475. These examples emphasize the stability of almandine and spessartine-rich garnets in normal regional metamorphism despite the often magnesium-rich environment in which they have developed.

TABLE I.

	(1)	(2)	(3)	(4)	(5)
SiO_2 .	27·49	52·14	51·89	37·45	54·56
Al_2O_3 .	3·74	1·82	7·21	20·08	5·02
Fe_2O_3 .	1·03	19·31	2·36	4·35	0·82
FeO .	29·93	16·03	18·68	15·05	16·12
MnO .	9·51	8·68	7·07	19·61	4·89
MgO .	6·03	0·14	9·18	0·30	14·99
CaO .	4·78	*nil*	0·93	1·86	0·38
Na_2O .	0·38	0·39	0·31	0·26	0·21
K_2O .	tr.	*nil*	0·81	0·57	0·76
$H_2O +$	0·81	0·81	1·33	0·22	1·67
$H_2O -$	0·05	*nil*			
CO_2 .	16·58	0·30			0·63
TiO_2 .	0·30	tr.		0·25	
Cr_2O_3 .	*nil*	*nil*	0·54	0·34	
SO_3 .	*nil*	*nil*			
	100·63	99·62	100·31	100·34	100·05

(1) Cummingtonite-garnet-sideroplesite-ankerite-schist, $\frac{5}{12}$ mile south-west of the outlet of Loch Bad an Sgalaig, Gairloch. Analyst, H. C. G. Vincent.
(2) Knebelite-magnetite band of quartz-knebelite rock, same locality. Analyst, H. C. G. Vincent.
(3) Cummingtonite-garnet schist, same locality. *Mem. Geol. Surv. Great Britain* (North-West Highlands), 1907, p. 83.
(4) Spessartine-almandine of rock (3) } *Mem. Geol. Surv. Great Britain* (North-West Highlands), 1907, p. 84.
(5) Cummingtonite of rock (3) }

Rocks of composition comparable to these Scottish cummingtonite assemblages have not frequently been encountered but reference may be made to the Homestake formation of the Black Hills, South Dakota, described by Gustafson (5). This formation is composed largely of a quartz-cummingtonite-biotite-schist containing locally garnet, chlorite, and carbonate. The carbonate-bearing members contain sideroplesite and in places hydrothermal ankerite associated with ore-bearing solutions. The original nature of these rocks is referred to a sandy clayey iron-magnesium carbonate sediment.

In Mysore state, cummingtonite-garnet-carbonate rocks have been described by Rao as occurring in bands or ribbons in crystalline limestones of the Kudurekanave Hills (6). These also are interpreted as derived by metamorphism of siliceous carbonate sediments. The carbonate associated with the cummingtonite is described as ferrodolomite and analytical data in support of this determination are provided by Rao, who considers that cummingtonite was developed by reaction of ferrodolomite with silica. A specimen of one of these rocks, kindly presented to the writer by Dr. Rao, was tested and found to contain, associated with cummingtonite and garnet, a carbonate of uniform composition—an ankerite with refraction $\omega = 1{\cdot}730$, corresponding to 60 per cent of ferrodolomite.

If the amphibole is derived from ankerite an equivalent quantity of calcite should be released and form a constituent of the ground mass in which the cummingtonites are developed. The available analyses of the carbonate minerals freed from cummingtonite and garnet do not show excess lime; the evidence is rather the converse. It remains as a further point of inquiry whether the cummingtonite and garnet have not arisen from original magnesium-iron carbonate (sideroplesite) in the sediments as in the case of the Homestake and Gairloch examples. That such carbonates do occur among these Mysore rocks is indicated by the record of banded sideritic cherts occurring with ferruginous quartzites among the crystalline limestones (6), pp. 18–19.

In discussing the ultimate sedimentary source of the eulysites and cummingtonite-grunerite schists of Loch Duich (2), p. 342, reference was made to three possible sources of the iron content: iron carbonates, greenalite, and iron oxide, and it was suggested that carbonates formed part at least of the original rocks though direct evidence was there not available. The rocks of Gairloch with their high content of sideroplesite and ankerite, add support to this conclusion, for from rocks rich in carbonates of this character have arisen petrographic types identical with some of those developed in the Glenelg area.

In the Gairloch district, within the band of sediments which contains the Loch Maree limestone and the cummingtonite rocks, occur the partly mylonitized quartz-magnetite-schists on the south-west side of Aundrary Wood. These are doubtless closely related in origin but deserve closer study. It remains to discover whether ferruginous and manganiferous sediments of the type now described form part of other sedimentary regions of the Lewisian—such as those of Tiree and Harris.

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Aluminous Pyroxenes in Metamorphosed Limestones.

By C. E. Tilley, with Chemical Analyses by H. C. G. Vincent.

THE name "fassaite" (Werner, 1817) was originally given to the leek- to dark-green pyroxene crystals of the Fassatal, characterized by a distinct habit with the zone [110] strongly developed. Subsequent to the analytical data of Doelter (1)[1] on the Monzoni fassaites the name has come to be applied more generally to alkali-poor aluminous pyroxenes found in metamorphosed limestones and dolomites. Doelter's analyses of the Monzoni fassaites date back as far as 1877 and are chiefly remarkable for their high alumina and ferric oxide contents.[2]

Although the pyroxenes of metamorphosed limestones can often be referred confidently in the absence of chemical analysis to diopside or hedenbergite with insignificant alumina, nevertheless optical data alone often provide little clue to the actual alumina content of these pyroxene minerals. A review of analytical data on limestone pyroxenes shows indeed that fassaitic (i.e. aluminous) pyroxenes are more widespread than is customarily expressed. The terms " diopside ", " hedenbergite " are often loosely used and reference is not infrequently made to assemblages of " diopside-spinel " in describing contact limestones. Separate analyses of such assemblages from limestone—though these associations are not uncommon—are apparently not available. A paragenesis of monoclinic pyroxene and spinel in a metamorphosed limestone opens up the question whether the pyroxene might not be expected to contain a significant alumina content. For this reason the composition of pyroxenes in equilibrium with a spinel phase is a point of some interest. Two well known parageneses of this type have therefore been examined analytically.

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[1] Numbers in parentheses refer to References at end of paper.

[2] An unfortunate transposition of the figures for lime and magnesia in a table of analyses in the original paper (1), p. 71, has resulted in some confusion in the subsequent literature, e.g. in Doelter's *Handbuch der Mineralchemie*, ii, 1, 1914, 558, this error is repeated and leads the author to comment on the magnesia-rich character of fassaite! Subsequent writers, Ledoux (2) and Cesàro (3), have discussed at some length the properties and constitution of fassaites basing their observations on these misquoted analyses!

The first "diopside-spinel" paragenesis studied is that of the regionally metamorphosed limestones of Ceylon described by Coomaraswamy (4) an example of which is figured in Harker's *Metamorphism*, 1932, 258, fig. 127. Analyses of both pyroxene and spinel from a pyroxene-spinel-calcite paragenesis have been made with results indicated in Table I.

TABLE I.

	1	1a			1b	1c	
SiO_2	49·55	1·815		2·00	1·92		
Al_2O_3	7·05	0·304	0·185 0·119	1·05	65·50	642	652
Fe_2O_3	0·79	0·022			1·60	10	
TiO_2	0·53	0·015					
FeO	1·72	0·052			10·09	140	634
MnO	n.d.				0·03	—	
MgO	15·57	0·849			19·78	494	
CaO	24·08	0·944		0·95			
Na_2O	0·12	0·008					
K_2O	nil						
H_2O —	0·08				nil		
H_2O +	0·92				0·83	$\mu = 1·744$	
	100·41				99·75		
Sp. Gr. at 20° C.	3·300				3·742		

1. Fassaite from fassaite-spinel rock, Adhekanwela, Ceylon, Anal. H. C. G. Vincent.
1*a*. Metal atoms on basis of 6 oxygen atoms.
1*b*. Spinel from the same rock.

A second example studied comes from the Monzoni contact zone. Though Doelter has supplied analyses of several Monzoni fassaites, the paragenesis of the minerals actually analysed is not clearly stated. The case studied is a pyroxene-spinel-calcite assemblage—similar to the rock figured in Harker's *Metamorphism*, 1932, 96, fig. 36. The results of these analyses of pyroxene and accompanying spinel are given in Table II.

Optical data on these analysed pyroxenes are as follows :—

1. Fassaite, Ceylon α 1·680 β 1·689 γ 1·706 $c \wedge \gamma = 43°$
2. Fassaite, Monzoni α 1·686 β 1·694 γ 1·712 $c \wedge \gamma = 43°$

The analysis of the Monzoni fassaite shows that the major part of the iron is in the ferric condition (Fe_2O_3 3·09, FeO 0·42) a feature revealed also in Doelter's original analyses of Monzoni fassaites.

TABLE II.

	2	2a			2b	2c	2d	
SiO_2	48·09	1·758	0·242	2·00	3·03	1·47		
Al_2O_3	7·61	0·329	0·087	1·02	64·44	66·37	651	660
Fe_2O_3	3·09	0·083			1·50	1·45	9	
TiO_2	0·49	0·013			nil	nil		
FeO	0·42	0·013			5·38	5·55	77	699
MnO	0·03	—			0·08	0·08		
MgO	15·11	0·829			24·58	24·89	622	
CaO	25·34	0·994	0·99		0·85			
Na_2O	nil	—			nil			
K_2O	nil				nil			
H_2O −	nil				nil			
H_2O +	0·41				0·69	0·70	$\mu = 1{\cdot}738$	
	100·59				100·55	100·51		
Sp. Gr. at 20° C.	3·319				3·624			

2. Fassaite from fassaite-spinel rock, Monzoni, Tirol.
2*a*. Metal atoms on basis of 6 oxygen atoms.
2*b*. Spinel from same rock.
2*c*. Analysis recalculated after removal of pyroxene of composition (2) equivalent to CaO 0·85 per cent.

The partition of magnesium and iron oxides between the pyroxenes and their respective associated spinels is given below.

	Ceylon fassaite.	Ceylon spinel.	Monzoni fassaite.	Monzoni spinel.
Total Fe as Fe_2O_3	2·70	12·81	3·55	7·61
FeO	1·72	10·09	0·42	5·55
MgO	15·57	19·78	15·11	24·90

In Table III (3–10) are set down eight analyses of aluminous pyroxenes selected from the literature. They show a considerable range in magnesia and ferrous oxide content and include an analysis by Doelter of fassaite from Monzoni with 10·43 per cent Al_2O_3. All these analyses conform reasonably well with the structural formula of pyroxenes.

As a group they are distinguished from aluminous pyroxenes of the omphacite type characteristic of eclogites by their lower

TABLE III.

	3.	4.	5.	6.	7.	8.	9.	10.
SiO_2	48·56	47·53	45·50	37·52	49·94	51·10	44·06	45·27
Al_2O_3	9·06	9·88	7·17	14·29	4·25	8·35	10·43	6·90
Fe_2O_3	1·68	1·79	0·60	4·43	4·76	2·40	5·91	7·41
TiO_2	0·57	—	—	5·72	—	—	—	—
FeO	0·36	0·91	15·59	7·12	5·15	3·43	1·67	21·07
MnO	—	—	—	0·14	0·50	—	—	—
MgO	14·89	14·43	8·45	6·72	12·54	9·12	13·10	0·51
CaO	25·16	25·46	22·25	24·06	23·29	22·89	25·20	18·45
Na_2O	0·09	tr.		0·09		2·48		
K_2O	0·04			tr.		0·11		
H_2O −	0·28	0·30		0·00			0·15	0·64
H_2O +								
	100·69	100·30	99·56	100·20	100·43	99·88	100·52	100·25
Sp. Gr.	3·308	3·312	3·291	3·43	3·388	3·273	2·965	3·40

3. Fassaite, Hodrusbánya, Hungary (5).
4. " Diopside " (fassaite), Italian Mt. Gunnison Co., Colorado (6).
5. " Augite," Arendal, Norway, Doelter (7).
6. Titanaugite, from limestone xenolith in norite, Haddo, Aberdeenshire (8), includes 0·11 Cr_2O_3.
7. " Hedenbergite," Renfrew, Ontario (9).
8. Pyroxene in limestone with garnet, contact of Realejo granite, Mexico (10).
9. Fassaite, Toal della Foja, Monzoni (11).
10. " Hedenbergite," Anhui, China (12).

silica percentages (44–50 per cent), omphacites (52–55½ per cent), and their insignificant content of alkalis. In contrast to the omphacites, the major part of the aluminium replaces silicon whereas in the omphacites it replaces in larger measure the elements of the Y group (Mg Fe Mn, etc.) at the same time Ca being partly replaced by Na. Certain analyses of pyroxenes from the limestones of New York State (*Annals N.Y. Acad. Sci.*, 9, 1896, 48) do not conform in this distinction. They contain up to 8·5 per cent Al_2O_3 and up to 56 per cent SiO_2, and show when determined low alkalis. These analyses show significant discrepancies when they are computed to the pyroxene structural formula and are not here further considered.

Analysis 6 of Table III is of special interest, not only on account of its high alumina content, but also of its high titanium content. Though pyroxenes of higher alumina content (with low alkalis) are known amongst igneous rocks (cf. Doelter's analysis of a Cape Verde Island basaltic pyroxene (13), p. 558, anal. no. 126) this Haddo pyroxene appears to be richer in alumina than other examples recorded from a limestone environment. Optically it is distinguished by being uniaxial and its mode of occurrence is suggestive both of high temperature of formation and of metasomatic reaction.

The analyses of Table III show that the alumina content of some of these pyroxenes exceeds that of the analysed example with a spinel paragenesis. The parageneses of the pyroxenes of Table III are not always clearly stated but it is known that some of them are associated with calcite, plagioclase, or grossularite or even form part of larger masses of " diopside rock ".

It is clear that high alumina may be found in the pyroxenes of hornfelses of classes 7–10. When the analyses of Tables I–III are plotted in the usual AFC diagram (Text-fig. 1) it is seen that they occupy a considerable field even in a simplified ternary system, thereby accounting in part for the common occurrence of two-phase assemblages as " diopside-plagioclase ", " diopside-grossular ", etc., in a polycomponent system.

It is to be noted that these high alumina pyroxenes belong to parageneses devoid of quartz. It is doubtful if such pyroxenes are stable in the presence of free silica.

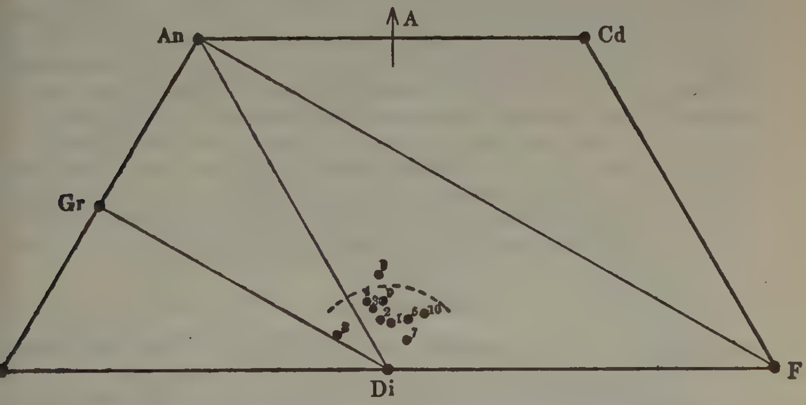

FIG. 1.—AFC plot of analyses of aluminous pyroxenes. Points 1–10 refer to analyses in Tables I–III. Di = diopside; Gr = grossularite; An = anorthite; Cd = cordierite.

In the four component system CaO-MgO-Al_2O_3-SiO_2 the join diopside-alumina passes in the plane of the spinel-anorthite-diopside field so that a " diopside with 10 per cent Al_2O_3 " could be expressed as a mixture of diopside, anorthite, and spinel. In the presence of free silica it appears not unlikely that such an aluminous pyroxene would be represented by a diopside-anorthite-enstatite assemblage.

It is impossible to predict from physical data alone the tenor of alumina in hornfels pyroxenes. As these examples show it may rise to 10 or more per cent and resort must be made to analysis. A detailed study of the synthetic system diopside-alumina is now in progress at Cambridge and this should provide valuable information on the optics of aluminous pyroxenes—data for which cannot as yet be correlated.

Note by H. C. G. Vincent.—Owing to the refractory nature of the spinels, determination of ferrous iron by the ordinary hydrofluoric acid method proved unsuitable. The Rowledge method (*Journ. Roy. Soc. W. Austr.*, xx, 1933–4, 165) for the determination of ferrous iron in refractory minerals was finally adopted. Using silica tubes and very finely ground spinel, conditions were found for complete decomposition of the spinel and solubility of the melt. Two determinations on the Ceylon spinel gave 9·94 and 10·24 per cent for the content of FeO. In the case of the Monzoni spinel the results were less satisfactory—two determinations giving 5·73 per cent and 5·04 per cent respectively. The mean of these figures has been taken. Pending further critical examination of the Rowledge method the figures obtained can be taken as approximate only, for apart from the difficulties of manipulation and trouble due to attack on the tubes, insolubility of the melt, and incomplete attack of the mineral, sources of error are likely to arise from failure to evacuate the tube and also from reduction of ferric compounds during fusion leading to high figures (cf. W. Suida, *Min. Mitt.*, 3, 1876, 175). This aspect of the problem is not discussed by Rowledge but no doubt has accounted partly for the absence of a reliable fusion method for ferrous iron in the past.

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REVIEWS.

The Pioneers in South African Geology and Their Work. By A. W. Rogers. Trans. Geol. Soc. S. Africa, Annexure to vol. xxxix, 139 pp. with portraits. Johannesburg, 1937.

At the request of the Council of the Geological Society of South Africa Dr. A. W. Rogers has employed some of his leisure in retirement in compiling this extraordinarily interesting volume. It will be generally agreed that no one could have been more competent for the task, and he had what is really a thrilling and romantic story to unfold. Apparently the first search for minerals by Europeans was made by order of van Riebeeck at Capetown in 1654, without much success, and it was not till the discovery of diamonds and gold that mining in South Africa became one of the great industries of the world. The modern period may be said to begin with Andrew Geddes Bain, who came to South Africa from Thurso in 1820 and began his explorations in 1826. However, he does not seem to have paid any attention to geology till about 1837. Thus one might almost say that serious geology in South Africa has just reached its centenary, so that the present publication is peculiarly appropriate. Bain was soon followed by a number of other well-known workers, Atherstone, Sutherland, Wyley, Rubidge, Stow, and Dunn. The last named, who began work about 1871, died only a few months ago in Australia at a great age. It is of interest to recollect that Mr. Dunn was the real inventor of the now world-famous name "Dwyka Conglomerate". Besides these several German and Austrian geologists, as a result of comparatively short visits, published papers of importance. Later came a great number of geologists who took part both officially as members of various geological surveys and as technical advisers in mining development: it is impossible to mention them individually, but it may be said there is perhaps no region of the world, and certainly none in the eastern hemisphere, where geology is such a living force and plays so important a part in the every day life of the people, as in South Africa. Therefore we welcome most heartily this record by a competent authority of its early history and development.

R. H. R.

THE GEOLOGY OF SOUTH-WESTERN ECUADOR. By G. SHEPPARD. pp. xiv + 275, with 195 figs. London: Murby and Co., 1937. Price, 25*s.*

MR. SHEPPARD has provided a convenient summary of the geology of south-western Ecuador, based partly on the scattered literature, but incorporating hitherto unpublished observations by himself and others.

The chapter on climate and physiography includes interesting sections on salt marshes, on the barrier beaches of the shore-line, and on the importance of the comparatively rainy years upon the topography of a semi-arid area. The lithology of the tertiary formations (Eocene to Miocene) is described in some detail, and the conditions of deposition discussed. Among the interesting phenomena described are the "undulose" bedding seen in some sandstones and shales, the "crush" breccias formed by the intrusion of dykes, and the Clay Pebble Bed of Ancon, which has been interpreted both as a thrust breccia and as a mudflow. Summaries of previous palaeontological works are given, with some new records; of exceptional value is Dr. Wayland Vaughan's chapter on the Tertiary

Larger Foraminifera. A chapter is devoted to the cherts and igneous rocks; it is claimed that "a field relationship exists between true chert veins . . . and certain igneous intrusions". In the chapter on Petroleum, the "geological fact, the intimate association of oil sands with the known areas of igneous intrusions" is discussed. A bibliography completes a volume which will no doubt stimulate research, as the author hopes, on the many problems to which he refers.

THE ATOMIC STRUCTURE OF MINERALS. By W. L. BRAGG. pp. 292. London: Humphrey Milford, Oxford University Press, 1937. Price 18*s*.

THE great mass of crystal structure analyses which are published year by year embrace many substances of mineralogical interest, but even more of which the importance is primarily purely chemical: and especially recently have the interests of the X-ray crystallographer been attracted more and more by the problems of chemistry rather than of mineralogy. The appearance of a work devoted solely to the structures of minerals is therefore most timely, not only in directing attention to the extent of the field already covered and of the problems yet to be solved, but also in providing, in a convenient and accessible form, an account of mineral structures otherwise available only widely distributed throughout the literature.

The treatment is primarily descriptive in its approach, and within this somewhat limited framework the structures of almost all minerals published up to the end of 1936 are discussed and fully illustrated by numerous diagrams. Roughly the first half of the book is devoted to minerals other than silicates and the second half to the silicates. In the first part the order follows closely that of the classical descriptive mineralogies, and the structures of the elements, halides, sulphides, oxides, and oxygen salts are discussed. Here it is a little disappointing to find that the chemical and physical significance of the structures is rarely considered at any length, and that apart from an occasional reference to the cleavage or optical properties practically no mention is made of the wider implications of the structures described. Thus, the type of binding-force operating in the various structures is rarely discussed, so that no attempt is made to classify these structures on any basis other than the very arbitrary one of chemical composition. Especially is this true among the sulphides where we find ionic, metallic, and homopolar crystals described without distinction. Above all to the mineralogist, whose study is so largely morphological, is a structural classification desirable.

In the section of the book devoted to the silicates the treatment is far more satisfactory, and here we welcome by far the most detailed account of the structural properties of these minerals yet published in the English language. The artificial chemical classification is replaced by the now classical arrangement of Machatschki, and it is interesting to see how strikingly this classification confirms the morphological classification of the mineralogist. In this section the chemical and physical implications of the structures are far more adequately discussed, and such features as cleavage, twinning, isomorphous substitution, and the rôle of water in the zeolites are given a structural interpretation.

The price of the book is high but this is doubtless inevitable on account of the numerous diagrams. Nevertheless it is questionable whether certain of the plates could not well have been eliminated without appreciable loss, especially as some of them are already easily accessible in *The Crystalline State.* The format is excellent and the binding strong, as is fitting in what is primarily a work of reference.

R. C. E.

DIE ENTWICKLUNG DER KONTINENTE UND IHRER LEBEWELT. By T. ARLDT. Second edition. Part i, 448 pp., 14 text-figs. Berlin: Gebrüder Borntraeger, 1936.

PALÄOGEOGRAPHIE UND TEKTONIK. By F. KOSSMAT. pp. xxiv + 413, 5 plates and 30 text-figs. Berlin: Gebrüder Borntraeger, 1936. Price RMk. 20.

THESE two works are alike in subject but entirely different in mode of treatment. Both writers recognize that there are several kinds of evidence which must be considered in attempting to restore the geography of a past period; but while Arldt lays stress especially upon the distribution of animals and plants, Kossmat gives most attention to tectonic changes and their effect upon the development of land-masses. In accordance with this difference in their approach to the subject Arldt begins his systematic part with the Kainozoic Era and Kossmat begins with the Archaean and Algonkian. The difference is indicated by the second part of the titles and the books are not rivals but confederates.

Arldt's work is a much enlarged edition of a book which originally appeared nearly thirty years ago and only the first part lies before us, but it is enough to show the scale of the work. There is an introductory section of 32 pages, and the rest is devoted to Kainozoic life in the Australian, Neotropical, and Madagascar regions. The amount of detail and the long lists of genera are sufficient to deter anyone except a systematic zoologist, but here and there the reader will find general conclusions which he can follow. They are not easy to find, for at present there is no index or table of contents available. The second part of the work is to complete the account of the Kainozoic and to deal with Mesozoic and Palaeozoic life throughout the world, and the more strictly geological matters are relegated to the third part.

Kossmat's book is much smaller and, to a geologist, much easier to read. It might, in fact, be placed in the hands of an advanced student to give him a general idea of the geology of the world without overburdening him with detail. The author takes each formation in turn and traces the broad features of the changes that took place during the period. He then gives an account of the present tectonic structure of the earth's surface, and ends with a very interesting summary. It is a book to read.

P. L.

COMPTE RENDU DU DEUXIÈME CONGRÈS POUR L'AVANCEMENT DES ÉTUDES DE STRATIGRAPHIE CARBONIFÈRE. Heerlen, September, 1935. Edited by W. J. JONGMANS. Tome i, 1937, 522 pp., 70 pls. Gebrs. van Aelst, Maestricht, Holland. Dutch fl. 17·50 (approximately $10).

THE complete *compte rendu* of this second International Carboniferous Congress will comprise three volumes representing over 70 contributions printed on 1,500 pages and 160 plates. The publishers announce that separate volumes cannot be purchased and that the " subscribers are bound to take all three volumes " which are of equal price ; thus the total cost will be about £6.

The *compte rendu* of the first Congress (1927) gave generalized accounts of the Carboniferous developed in most western European countries and regional correlation of zonal faunas and floras was attempted. The second Congress aimed at discussing the Carboniferous geology of the whole world ; comparisons were made between the succession of fossil assemblages in western and eastern Europe, between those of Europe and America, and also with the Asiatic fossil floras, particular attention being paid to the characters and correlation of the four Permo-Carboniferous floral provinces characterized respectively by the Euramerican, Angara, Cathaysia (*Gigantopteris*), and the Gondwana (*Glossopteris*) floras. The peculiar distribution of the Cathaysia flora has produced interesting speculations concerning the effects earth-movements have had on the present location of Permo-Carboniferous deposits. Several contributions deal with the morphology and evolution of the Pteridosperms and others with the petrology of coal.

A useful summary by W. J. Jongmans and W. Gothan outlines the results of the Congress under twelve headings ; some of the decisions are recorded here. The Devonian-Carboniferous boundary in western Europe was defined at the summit of the Strunien (Assise d'Etroeungt = K of Vaughan's Zonal scheme, leaving these faunally transitional beds in the Devonian and starting the Carboniferous at the base of the *Gattendorfia* Zone represented in the Hangenberg Kalk of the Cephalopod facies of the German Carboniferous ; the correlative of this zone in Vaughan's scheme is Z_1. A tripartite division of the Dinantian was adopted on the basis of the "international" zonal divisions (*Gattendorfia* Stufe I, *Pericyclus* Stufe II, and *Goniatites* Stufe III) in preference to the "regional" divisions Tournaisian and Viséan. The Westphalian, which of late has been divided in continental Europe into three major divisions, A, B, and C, separated by widespread marine horizons, is now to be divided into four, the division C giving place to C and D, which are separated on floral grounds, although the precise boundary remains unsettled. Similar uncertainty exists concerning the place of the Westphalian-Stephanian and the Stephanian-Permian boundaries. These problems await further discussion at the next Congress. Jongmans (p. 357) prefers to retain the term Stephanian for a specialized facies rather than for a general subdivision of the Carboniferous.

Among the excellent half-tone plates given in the first volume are 25 illustrating characteristic Namurian and Lower and Middle Westphalian plants of Europe and America. The volume gives every promise that the complete work is well worthy of a place in every important geological reference library; it is to be regretted, however, that the publishers have not issued the book bound in stiff covers.

C. J. S.

THE GEOLOGY OF EGYPT. By W. F. HUME. Volume II: The Fundamental Pre-Cambrian Rocks of Egypt and the Sudan; Their Distribution, Age, and Character. Government Press, Cairo, 1934–7.

Part 1: The Metamorphic Rocks. pp. lxv + 300 + 124 (Index), pls. i–xcvi. 1934. £E3.

Part 2: The Later Plutonic and Minor Intrusive Rocks. pp. xxxv + 301–688 + 107 (Index), pls. xcvii–clviii f. 1935. £E3.

Part 3: The Minerals of Economic Value. pp. xxxv + 689–990 + 75 (Index), pls. clix–cxcvi. 1937. £E2,50.

THE second volume of the *Geology of Egypt* surpasses the first (1925) in illustration and in detail. The illustration is the feature which strikes the reader most, since there are numerous coloured plates of rocks, minerals, and thin sections (about forty-five double plates and fourteen single), together with a large number of photographs of geological features of the Eastern Desert, and copious maps. The text is partly original, utilizing unpublished work covering the Eastern Desert and Sinai (the sections dealing with the Nile Valley south of Aswan (W. Halfa nearly to Khartum) are largely new), and partly compiled with lavish quotation from other works on the region. In addition the third part deals broadly with archaeological matters in which the geologist can occasionally furnish valuable help, and many beautiful coloured plates are given of antiquities in the Egyptian Museum. The index is voluminous, there being a total of 306 pages in the three parts (against 990 pages of text).

The subject-matter is divided among the three parts as follows:—the pre-Carboniferous sediments (metamorphosed for the most part) and older intrusions in Part 1, the younger pre-Carboniferous intrusions in Part 2, and useful deposits in Part 3. Extensive quotation from previous publications of the Geological Survey and from other works caters for a local difficulty of inaccessibility of much of the literature dealing with the region in Libraries.

The illustration of the rock-specimens and sections is attractive and the rendering of these in colour a remarkable feat of printing. It is, however, a moot point whether coloured illustration of rock slides is worth the heavy cost. The reviewer finds the excellent illustrations of the previous standard works on the rocks of the region (Ball's memoirs on the Aswan Cataract and the S.E. Egyptian Desert) of such value that it seems a pity that those which were not replaced by coloured figures were not also republished, especially since these works are out-of-print and practically unobtainable locally. One of the coloured figures is either drawn from an unusually thick slide, or under parallel Nicols (pl. xl, fig. 2). The maps and diagrams are abundant, many of them new, and those printed in colour are well up to the high standard generally found in the Survey Department's publications. Among the republished maps there are one or two noteworthy absentees, such as Barron's map of S.W. Sinai, and the map of the "Oilfields Region" by Ball, which contains a large area of pre-Cambrian formations. Barthoux's map of the W. Natash–W. Shait region has been redrawn (pl. cxxviii), but two formation-names have been omitted from the legend—mugearite (oblique N.W.–S.E. lines) and "*gneiss amphibolique*" (interrupted vertical lines).

The pre-Carboniferous (generally considered to be pre-Cambrian) rocks of the region are classified into three main divisions—Protarchaean (oldest), Metarchaean (middle), and Eparchaean (younger), with a fourth group of post-Eparchaean intrusions called Gattarian (Part 2). The Protarchaean is defined as consisting generally of gneisses of "fundamental" type (comparable with the Lewisian), and the Metarchaean consists of both ortho- and para-schists between the Protarchaean and Eparchaean. The last is defined by reference to the well-known Hammamat series, whose typical member is the conglomerate known as the *breccia verde* (*antico*) *d'Egitto*, and also the series of lava-type rocks and tuffs, regarded by Barron and Hume as interbedded with volcanic conglomerates, and by Barthoux as later than (the lava-types intruded into) the conglomerates, in the northern region of G. Dokhan and the Ferani hills of S.E. Sinai. Other volcanic conglomerates are also included in this series, in isolated outliers in the central and southern Eastern Desert. These rocks are not metamorphosed (*vide* description in the appendix, p. 295) and consequently the use of schist to describe the Hammamat rocks (pp. 259, 263, 265, 865) is misleading. The unconformity implied in Barthoux's recognition of an older lava-series and older granites among the boulders of the Hammamat (Eparchaean) conglomerates is not discussed. It appears that the present state of knowledge of stratigraphical relations in the Eastern Desert and Sinai is very sketchy, since field-relations between the different groups are not known, and no clear idea is yet possible of the relations of the apparently non-metamorphic Eparchaean and the largely metamorphosed Metarchaean formations. In the same way the separation of the Protarchaean from the Metarchaean is largely based on crystallinity and not on observations of field-relations. The three-fold classification is therefore a useful scheme, forming the basis of future work, but cannot be said to provide a stratigraphical table for the pre-Cambrian rocks yet. This is clearly the result of the inaccessibility of the region, and the sum of our knowledge is the result of traverses and reconnaissance surveys, few maps of the region being detailed in the sense generally applied in western Europe. The distribution of the Protarchaean rocks in the Eastern Desert has been indicated by a sketch map (pl. xxxvi), and part of the area occupied by the Eparchaean is shown (pls. lxxvi, xlii), and the areas not shown thus may be considered Metarchæan. The reprint of Little's map of the region on a scale of 1 : 2,000,000 shows the pre-Cambrian undivided save for some areas of "post-Archaean volcanic rocks" (pl. i) but the volcanic rocks of Cretaceous age in W. Natash are not shown.

The intrusions of the region are partly of Protarchaean age, partly Metarchaean, and the larger number appear to fall in the post-Eparchaean division, the Gattarian. The Protarchaean intrusions are not separable from other gneisses, with the exception of certain ultrabasic schists (p. 17) and granite gneisses (p. 685). The Metarchaean intrusions include Barthoux's older granite and older volcanic series, and a variety of bedded basic schistose rocks originally doleritic in composition in the schists. The Gattarian is described in Part 2, but the order is somewhat different from that given in Part 1 (p. 16), and in any case appears somewhat arbitrary, since little field-evidence of relative age is quoted. Ball's scheme, which classed rocks according to systematic grouping, seems safer where the relative age is so much in doubt, but Hume adopts the age-grouping suggested by Barthoux, filling it out from his wider knowledge of the region. The position of the alkaline rocks given in the earlier part is altered in Part 3, where they are placed later in the Gattarian (p. 810). Information about the nature of the country-rock of the intrusions is generally wanting, but this omission is repaired in the case of the Sinai intrusions (pp. 613–17) which were originally mapped by the author. The gneiss generally known as the "Chephren Diorite" is included in the Gattarian among the diorites (p. 313), though Little and Barthoux showed the rock to be anorthositic.

An inconsistency appears in the description of the Gebel Abu Khrug gabbro, placed among the Protarchaean gneisses in Part 1, but later transferred to the Gattarian. In the first description (p. 73) the locality is stated to be "from a low hill north of Gebel Abu Khrug", but in the second "obtained from a gneissose mass occurring to the south of Gebel Abu Khrug" (p. 428), a difference of 8 km. according to Barthoux's map of the region (pl. cxxviii).

The last part of the volume deals with much that is of minor interest to the geologist, but a section is devoted to the mineral wealth of the country. Much of the descriptive matter has not been published before. The summary of the geological features of the gold ores, now recovering their importance in the economic life of the country, contains an important generalization, that the gold is confined to the Metarchaean (p. 805), which, if substantiated, narrows down the field for prospecting considerably, and also suggests that a new attack on the mapping of the Metarchaean should be made in the near future. The other mineralizations—molybdenite, wolfram, and tinstone—belong to the Gattarian. Chromium ores are already mentioned in connection with the ultrabasic rocks of the Protarchaean and the Gattarian.

The volume marks an important stage in the knowledge of the pre-Cambrian rocks of Egypt, among which there is a hint of organic remains described by Barthoux (p. 635), and puts a fitting period to the first stage of geological surveying in the deserts of Egypt and Sinai. As the author remarks, the work of the survey was done under difficulties which do not hamper the modern research worker, who covers distances in a day which were formerly only possible with weeks of slow progress. Preliminary survey was also in the main a topographical survey, and geology became relegated to a secondary place, and only too often consisted in the mere collection of specimens. The work of the surveyors is described in many other publications, and the topographical maps now being produced are largely the publication, long after the original workers have left the country, of this early reconnaissance. Now that modern maps, and a recrudescence of interest in mineral resources, are providing a stimulus to research in the desert-regions, it is to be hoped that the foundation laid by this work will soon be amplified and our knowledge of the region brought into line with that of the more southern parts of Africa.

G. A.

CORRESPONDENCE.

PERTHSHIRE TECTONICS.

SIR,—A paper entitled "Perthshire Tectonics: Schichallion to Glenlyon" has recently been published by Drs. Bailey and McCallien.[1] As my previous work in the area is very frequently referred to,[2] and alterations in my interpretation have been made, perhaps you will allow me space in which to reply to them.

Credit has been given to me for noting the uniformity of the pitch of the small folds, throughout the district. The authors, however, imply that, after making this observation, I have failed to draw the obvious deductions. On the evidence of the pitch they regard the Beinn a' Chuallaich fold as being a "synform". In this I am now inclined to agree with them. In the same way the Bailliemore structure may be an "antiform". Partly on this evidence they regard all the country between the synform and the eastern Dalradian boundary as being inverted. If, however, the reader of their paper will consult Fig. 3 (p. 83), he will notice the following. In the south-west corner of the area of the text-figure, pitch carries (1) Grey Limestone under Banded Group, and (2) Banded Group under White Limestone and Boulder Bed. This is well within the "inverted" area, and yet, on the authors' own principle, the beds must be here uninverted.

The structure must therefore be more complicated than Drs. Bailey and McCallien have imagined. The authors proceed to argue from the inversion that there is a marked recumbent fold in this district. Some overfolding exists, but not, according to visible indications, of a type that can reasonably be called recumbent. Its extent has also, in at least one respect, been exaggerated. As it affects the Moine-Dalradian boundary, surface evidence shows that there is overfolding of about 1¼ mile. The authors' diagram (Fig. 15) shows this as having increased southwards, without apparent reason, to 3½ miles.

The following sentence appears in the summary of conclusions: "Throughout, the big movements have been towards the south-east, with local twists and adjustments." In the area of what Dr. Bailey has termed the "Loch Tay Inversion", this statement may be justified. Farther north, however, the structure becomes more complicated. The study of lineation, in its bearing on Highland problems, is at present only beginning. Its effects may well be revolutionary, and it might be advisable to await the result, before making generalizations of this sort.

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[1] Bailey, E. B., and W. J. McCallien, *Trans. Roy. Soc. Edin.*, 59, pt. 1, 1937, 79.

[2] Anderson, E. M., "Geology of the Schists of the Schichallion District (Perthshire)," *Quart. Journ. Geol. Soc.*, 79, 1923, 423.

I do not think that the Dunalastair belt of Grey Schist and Limestone, etc., to the north of the Tummel, is in the centre of a synform, nor that it is bounded to the east by a strip of Banded Group. My own field maps seem here to be widely different from those of the authors. The appearance of regularity which has been given to the outcrops of the different formations within this belt is, in my opinion, deceptive. Nor do I think that the authors have understood the structure of this part of Perthshire so thoroughly as to be able to claim that they have made " an important advance on Anderson's position ".

E. M. Anderson.

ZONAL POSITION OF THE ELSWORTH ROCK.

Sir,—I would like to ask Dr. Spath for the reference to any previous publication of the main thesis of my article (since he asserts it contains nothing much that is new): namely, that at Elsworth two distinct zones (*cordatus* and *plicatilis*) are represented, unmixed, in condensed ironshot facies, that the Elsworth Rock belongs to the *plicatilis* zone only, that the ironshot rock at Upware belongs only to the *cordatus* zone, and so is not the Elsworth Rock-equivalent, which at Upware is the Coralline Oolite. The passages I have quoted from the Cutch Memoir show that Dr. Spath regarded the ironshot rock at Upware as the Elsworth Rock, and the Elsworth Rock as containing a mixed or derived fauna.

Certainly the zonal position of the Elsworth Rock (*at Elsworth*) as given in Dr. Spath's memoir is unassailable, and it has not been assailed. In this particular his correlation agrees with that of his predecessors, Rigaux, Wedd, and myself.

Dr. Spath, without attempting to justify it, brings against me a serious charge of making " an entirely one-sided and misleading selection of passages and species and even dates of publication ", only to use them as skittles. In my article only two passages from his work are quoted. They are consecutive passages and are quoted *en bloc*, without expurgations. The quotations form a natural part of the introductory review of previous work, in order of dates of publication. They are the only passages that are relevant to the matter in hand. No species are " selected ", for none are omitted—unless Dr. Spath is suggesting that I ought to have reprinted his separate list of thirty-nine species from Elsworth and St. Ives. Believing 72 per cent of those items to stand in need of alteration, I considered it preferable only to refer to it and give my new list.

W. J. Arkell.

University Museum,
Oxford.
8th December, 1937.

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ORIGINAL ARTICLES.

A Section of Rhaetic and Associated Strata at Chipping Sodbury, Glos.

By S. H. Reynolds, Emeritus Professor of Geology in the University of Bristol.

(PLATE IV.)

I. INTRODUCTION.

IN 1904 the late Dr. Arthur Vaughan, in collaboration with the writer, described[1] the Rhaetic rocks exposed in constructing the South Wales direct branch of the Great Western Railway between Stoke Gifford and Chipping Sodbury. During the last few years, extension of the big quarry in Carboniferous Limestone at Chipping Sodbury has exposed a fine section of Rhaetic, the description of which and of the field relations of the associated rocks is the object of the present paper.

II. THE PALAEOZOIC SURFACE.

The surface of the Carboniferous Limestone on which the Secondary rocks rest has some interesting features. Along the western margin of the quarry the surface is very uneven and shows all the features of a subaerially eroded area. Resting on the Carboniferous Limestone is a section of Keuper consisting of bands of calcareous sandstone and marly beds weathering yellow alternating with more shaly material. Near the northern end of the section the base of the Keuper becomes conglomeratic. It is difficult to ascertain the thickness of the Keuper, which varies in different parts of the section and in correspondence with the uneven floor on which it rests, but it may be taken at about 25 to 30 feet. No Rhaetic rocks are seen here *in situ*, but there is a big dump chiefly of Rhaetic material brought from the other side of the quarry.

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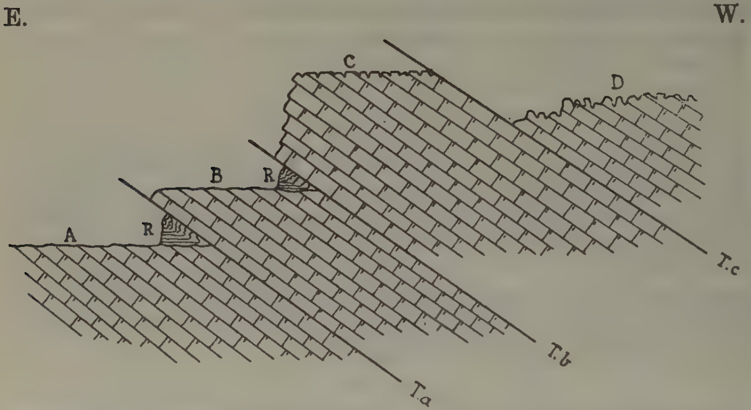
[1] *Quart. Journ. Geol. Soc.*, lx, 194–212.

The Palaeozoic surface of the quarry as a whole contrasts strongly with that of the western margin in being planed down to a horizontal platform on which along the eastern border the Rhaetic beds rest directly. This planing down, or at any rate the later stages, can only be attributed to the Rhaetic sea. The platform is being rapidly cut away by quarrying operations. The surface of the limestone in this part of the quarry is in the main very smooth and level save that an interbedded band of massive grit resisted the planing-down action of the Rhaetic sea and until removed by quarrying stood out above the general surface. The same band was prominent in the Sodbury railway cutting and is indicated about 100 yards east of Lilliput bridge (in the section, Vaughan and Reynolds, op. cit., p. 198).

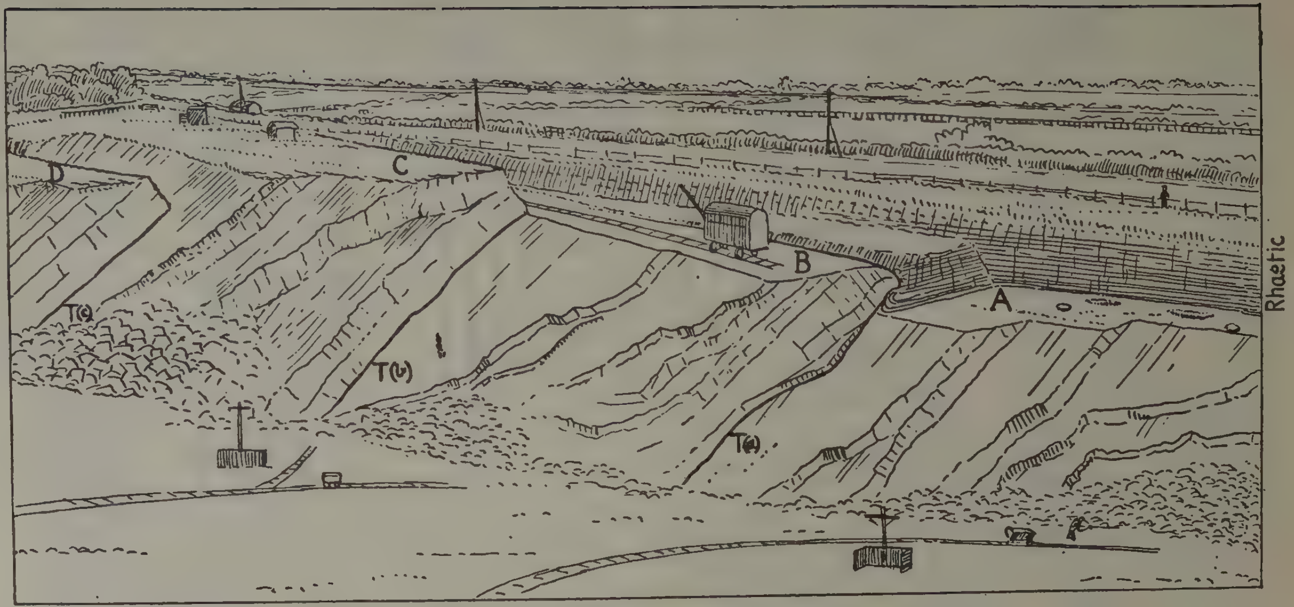
Along the northern margin of the quarry the fact is conspicuous that the surface of the limestone is not all at the same height above the sea, but that it forms four platforms standing at four different levels (see Text-figs. 1 and 2 and Pl. IV). The highest platform C is about 6 feet higher than D which lies farther west, and 17 feet higher than B which lies farther east, while B is about 8 feet higher than A, the level of the eastern margin. These facts are admirably shown in the perspective view (Text-fig. 2).



Text-fig. 1.—Section (looking south) showing the overthrusts in the N.E. corner of Chipping Sodbury quarry, vertical scale, 1 in. = 27½ ft. A, B, C, D, Carboniferous Limestone platforms; C, somewhat griked; D, more deeply griked. T.a, T.b, T.c, overthrusts; R, pockets of disturbed Rhaetic. (Compare Pl. IV, fig. 2.)

These differences of level are clearly the result of three thrust faults, well-seen when the section is viewed from the floor of the quarry and indicated by T.a, T.b, and T.c, in Text-figs. 1 and 2.

A cutting back of the platform B early in 1937 displayed a remarkable section clearly showing the thrusts T.a and T.b (Pl. IV, fig. 2) Most of the Rhaetic material which, when the perspective view was drawn was still in place on the platforms B and C, had by the



TEXT-FIG. 2.—Perspective view of Chipping Sodbury quarry, looking N.N.E.
A, B, C, D, Carboniferous Limestone platforms. T.a, T.b, T.c, overthrusts.

beginning of 1937 been quarried away, leaving only pockets of highly disturbed shale under the thrust masses of limestone.

The great majority of the disturbances affecting the Carboniferous Limestone rocks of the Bristol district are clearly Armorican and in the case of overthrusts the movement came from the south-east, or in some cases more nearly from the south and in others from the east. In the present case if the movement is one of overthrusting it came from the west. If, however, as Professor Trueman suggests, the thrusts are not over- but underthrusts, the movement was from the east. The fact, however, that the disturbance is obviously post-Rhaetic makes it futile to attempt exactly to parallel it with the Armorican movements.

Reference may be made to the fact that when the Sodbury railway cutting was under construction at the beginning of the century a section of Lias faulted and thrown into a sharp fold was exposed. The axis of this fold would, if prolonged, pass very near the line of disturbance now being described.

The movement in the case of each of the thrusts T.a, T.b, and T.c (see Text-fig. 2) took place along or practically along bedding planes which may show considerable slickensiding along the lines of thrust. The dip-joint faces also show slickensiding which Professor Trueman points out is best seen in the west side of the quarry where there was probably considerable differential movement between different parts of the same bed.

The upper surface of the Carboniferous Limestone varies greatly in accordance with the presence or absence of the Rhaetic beds. East of the middle thrust T.b Rhaetic beds rest or formerly rested on the limestone and the thick mass of impervious clay which they include has entirely prevented any percolation of surface water. The limestone is quite unmarked by solution channels. West of the middle thrust T.c the limestone was overlain only by the surface soil and this being highly porous the surface is deeply griked by solution channels.

III. Succession of the Secondary Rocks.

The general succession is as follows :—

Lower Lias represented by blocks of pale grey limestone in the surface soil. (No " Sun bed " or Cotham Marble.)	*Pleuromya tatei* Rich. and Tutcher. *Modiola minima* Sow. *Ostrea liassica* Strickl.

Upper Rhaetic.	*thickness.*	
8. Pale shale.	2 0	
7. *Estheria bed;* compact pale argillaceous limestone somewhat irregular and variable in thickness.	up to 1 0	no recognizable fossils found
6. Greyish shale.	2 6	

Lower Rhaetic.	*thickness.*		
5. Irregular band of greyish argillaceous limestone sometimes becoming sandy.	0	6	*Chlamys valoniensis* (Defr.) (very common) *Schizodus* sp. *Schizodus* cf. *ewaldi* Bornemann (very common) *Dimyodon intus-striatus* Emmrich (common)
4. Dark shale, sometimes very fissile with much selenite especially in the lower part. Low down in this band is an impersistent ferruginous layer variable in thickness and full of vertebrate remains.	3	6	*Cardium* sp. *Myophoria emmrichi* Winkler *Protocardium rhaeticum* (Merian) *Acrodus minimus* Ag. (very common) *Saurichthys acuminatus* Ag. (very common) *Sargodon tomicus* Plieninger *Gyrolepis alberti* Ag. (common) *Plesiosaurus* sp.
3. *Pecten bed*; argillaceous limestone sometimes very hard and crystalline, not markedly pyritous. Prominent layers of "beef" in relation to upper and lower surfaces.	up to 1	0	*Chlamys valoniensis* (very common especially near the base)
2. Dark shale divisible into :—			
(*c*) dark grey shale with several bands crowded with fossils.	4	6	*Pteria contorta* Portlock *Chlamys valoniensis* *Protocardium rhaeticum* *Schizodus ewaldi* (very common)
(*b*) compact black shale, somewhat pyritous, very fossiliferous.	3	0	*Pteria contorta* (very common) *Schizodus ewaldi*
(*a*) black very papery shale, no fossils found.	1	3	
1. Bone-Bed very irregular and patchy, thickness variable.	1	0	or less

The Bone-Bed shows two types of development. In its normal development it very closely resembles that formerly exposed in parts of the Sodbury railway cutting and consists of a dark somewhat crystalline limestone full of vertebrate remains and including numerous coprolites and small pieces of phosphatized bone.

The second type of Bone-Bed is patchily developed and occurs near the outcrop of the massive grit band in the Carboniferous Limestone to which allusion has already been made. This band gives rise to numerous blocks (seen in Pl. IV) generally well rounded and of all sizes up to a length of some 4 feet and a thickness of upwards of 2 feet. These blocks rest on the planed-down surface of the limestone, being sometimes isolated from one another sometimes closely packed. When the latter is the case bone-bed material accumulates between the blocks cementing them together and producing a conglomeratic bone-bed similar to that at Aust only far coarser. When associated with the blocks the bone-bed material has the same calcareous character as elsewhere in the section, but vertebrate remains are less plentiful. The blocks are often partially coated with pyrite while in parts of the section a pyritous crust generally about ¼ in. thick in which the teeth of the Rhaetic fish may be recognized rests on the Carboniferous Limestone. Of vertebrates all the forms recorded as occurring in band 4 were found and in addition the teeth of a small *Hybodus* and the vertebrae termed *Rysosteus*. *Ceratodus* was not found. Quartz pebbles up to an inch in length were fairly common.

IV. Comparison with the Railway Sections.

Two neighbouring railway sections of Rhaetic rocks are described in the paper quoted above, one west of Lilliput bridge, one north of Kingrove Farm. The section now described lies about half a mile north of them. The Lilliput section was already considerably overgrown when described in 1904. Both are now entirely overgrown.

The table below shows the chief points of difference and agreement in the three sections.

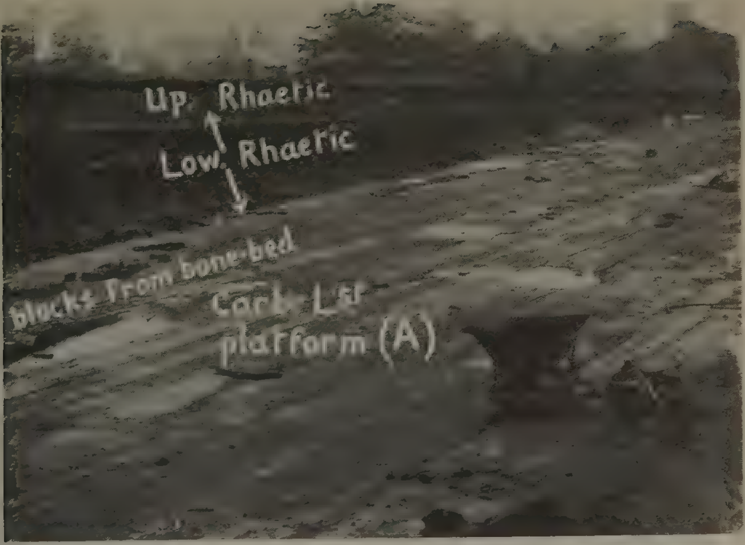
Sodbury Quarry.	*Lilliput.*	*Kingrove Farm.*
No "Sun Bed" or Cotham Marble seen.	Compact Limestone ("Sun Bed") present with doubtful representative of Cotham Marble.	Cotham Marble well developed.

The Upper Rhaetic in all three sections consists of grey shale with pale argillaceous limestone.

<table>
<tr><td colspan="2">The Lower Rhaetic at Sodbury quarry and Lilliput consists of black shale with a band of dark crystalline limestone, the "Pecten Bed" ("Lower Pecten Bed" of Aust). Bands of fibrous carbonate of lime ("beef") are characteristic.</td><td>The Lower Rhaetic does not include any conspicuous bands of dark crystalline limestone.</td></tr>
<tr><td>Bone-Bed well developed.</td><td>No Bone-Bed seen.</td><td>Bone-Bed well developed.</td></tr>
</table>

V. Conclusion.

In conclusion the writer wishes to tender his heartiest thanks to Professor A. E. Trueman for drawing Text-fig. 2, and for giving the benefit of his opinion regarding the disturbance of the strata; to Mr. J. W. Tutcher for determining the invertebrate fossils; to Dr. Stanley Smith for help in the field and to the General Manager of the Chipping Sodbury quarries for affording every facility for the work.



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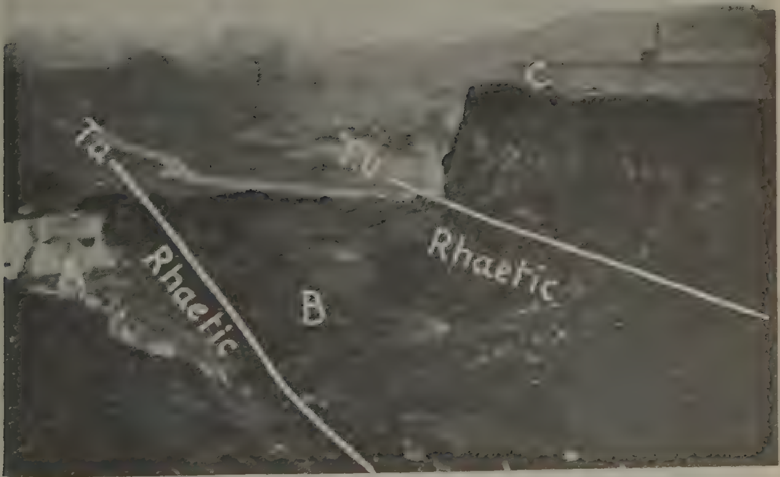

Photo S. H. R.

2

CHIPPING SODBURY QUARRY.

1.—Shows the Rhaetic section resting directly on the very level Carboniferous Limestone platform (A).

2.—Shows the relations of the three Limestone platforms A, B, and C and of the pockets of Rhaetic below the thrusts T.a and T.b (cf. fig. 1).

[*To face p.* 102.

On the Discovery of Lower Carboniferous Tillites in the Precordillera of San Juan, Western Argentina.

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(PLATES V AND VI.)

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I. INTRODUCTION.

THIS paper gives an account of an investigation of the Carboniferous glacial deposits that crop out along the valley of the Arroyo de las Cabeceras, which is situated in one of the western front ranges of the Precordillera of San Juan, Western Argentina. The field work was carried out by one of us (J. Keidel) and the detailed examination of the fossils collected by the other (H. J. Harrington).

The Arroyo de la Cabeceras is almost the only permanent water course in a region of very dry climate. Having its source high up in the Sierra de Tontal, it flows towards the S.W. and ends, by infiltration and evaporation, in the " bolsón "[1] of Leoncito Abajo or Llanos de Leoncito, within the broad intermontane basins that are situated between the Precordillera and the Cordillera of the Andes. Notwithstanding its small volume of water, it cuts through the above mentioned front-range in a sometimes broad transverse valley. This valley, as well as the mountain range which it traverses, is separated from the group of high elevations known as the Sierra de Tontal by the longitudinal basin of the " Valley of the Cabeceras ".

The transverse valley of the Arroyo de las Cabeceras lies some 25 km. S.S.E. of Barreal, the well known locality from which an Upper Carboniferous or Lower Permian marine fauna was collected by du Toit and described by Cowper Reed (1927). The hamlet of Leoncito Encima is situated in this valley, and it lies some 60 km. S.S.E. of the confluence of the River de los Patos and the River Castaño with the San Juan River.

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[1] The Spanish word " bolsón " has long been in use by S. and N. American geologists to indicate undrained basins deeply filled up with wash from the surrounding mountains. A discussion of the term will be found in : Tolman, C. F., " Erosion and Deposition in the Southern Arizona Bolsón," *Journ. Geol.*, 1909, xvii, 139.

Upper Paleozoic glacial deposits are exposed in several places in this valley, where they were first discovered by Keidel in 1914. In a later paper (1922) on the distribution of the glacial deposits then known in the Argentine, all of which were at that time considered to be Permian, he mentioned tillites from three different localities. One of these lies near the hamlet of Leoncito Encima, on both sides of the Arroyo de las Cabeceras. Another, with the largest outcrop, is located in the S.W. extremity of the Ciénega del Medio, some 3 to 4 km. up-stream from Leoncito Encima, while a third one is found 2·5 km. down-stream from Leoncito, on the right bank.

Later du Toit (1927, p. 33), in the belief that he had discovered it for the first time, briefly described the outcrop of the Ciénega del Medio and indicated its position in a geological sketch-map; he also made a passing reference to the exposure of Leoncito Encima.

II. GEOLOGICAL SKETCH OF THE VALLEY OF THE ARROYO DE LAS CABECERAS.

The transverse valley of the Arroyo de las Cabeceras is some 7 or 8 km. long. Running E. and W. with a variable deflection towards the S., it cuts through the most westerly range of the Sierra de Tontal.

We can distinguish two sections in this valley which differ in morphological configuration and geological constitution.

The upper section extends from the S.W. extremity of the Ciénega del Medio to within a short distance above Leoncito Encima. From here the lower section runs to the N.E. boundary of the " bolsón " of the Llanos de Leoncito.

The steep and rocky slopes of the upper section of the valley are formed by beds of dark coloured greywackés and slates as well as by sandstones, greywackés, arenaceous slates, and similar sediments of lighter colours. These beds belong to Palaeozoic series of various ages.

Greenish coloured and purplish red phyllitic slates are, in some places, associated with the dark coloured greywackés. This same association of strata occurs in many places of the western mountain ranges of the Precordillera, especially to the S. of the San Juan River. Notwithstanding great deformation due to repeated folding, it is easily identified by its lithological characters, even in widely separated outcrops. Hitherto no fossils have been found in these beds. According to Bodenbender and Stappenbeck (1911, p. 26) they should be considered as marine Devonian sediments, an opinion that has been accepted, with some reservation, by du Toit for the greywackés and slates that crop out near the tillite of the Ciénega del Medio.

The age of this series, however, is still unknown, although it must be older than the tillites of any of the outcrops of the valley of the Arroyo de las Cabeceras. This follows from the unconformable disposition, already observed by du Toit, of the tillites of the Ciénega del Medio on the greywackés and slates, and by the fact that many of the boulders and pebbles in the tillites of the different outcrops are derived from those greywackés.

The slopes of this section of the valley are formed mainly by the lighter coloured strata among which yellowish brown and yellowish grey sandstones, greenish grey greywacké-sandstones and micaceous sandstones in thin layers are conspicuous and easily distinguishable from the dark greywackés and slates already mentioned. These beds are also of Palaeozoic age, but, with the exception of some indeterminable plant remains found in a greenish grey greywacké-sandstone, they have not yet yielded fossils.

Strata similar to these also crop out in the lower section of the valley, forming a low marginal elevation in the N.E. boundary of the " bolsón " of the Llanos de Leoncito. In this section, some 2·5 to 3 km. long, the stream has deepened its bed in thick accumulations of fresh-water deposits and detritus of alluvial cones that may be provisionally referred to the Lower Pleistocene. Yellowish grey sandstones, greenish grey slates, and other Palaeozoic strata emerge, in scattered outcrops on the N. side of the valley, from beneath these conglomerates and detritus. These rocks are related, at least in two places, to grey and ochre-grey glacial deposits which contain well striated pebbles.

The number of outcrops of tillites and fluvio-glacial conglomerates in the valley of the Arroyo de la Cabeceras is, thus, unexpectedly large, and it is quite possible that the various tillites related to the different types of strata are not only of Lower Carboniferous age, such as those of Leoncito Encima, but also Upper Carboniferous like those of Barreal, and even Lower Permian.

The scarcity of fossils makes it very difficult to distinguish the different Palaeozoic series present, but an even more serious obstacle arises from the great tectonic complications due to movements of several Upper Palaeozoic phases. Signs of strong folding and deformation are observable in many of the outcrops of the upper section of the valley as well as in the strata forming the marginal elevation, near the " bolsón " of the Llanos de Leoncito, at the western end of the lower section. The occurrence of movements prior to the Carboniferous glaciations and to the last great foldings and thrustings of the Palaeozoic Era is deduced, in this region of the Precordillera, from the unconformity that separates the tillite of the Ciénega del Medio from its floor of dark greywackés and slates.

The outcrop of thick tillite extends from E.S.E. to W.N.W. as is approximately shown by the geological sketch-map of du Toit (1927, p. 33). A sort of stratification due to variations of the texture and of the resistance to erosion enables us to observe a change of strike in the tillite. Near the eastern end of the outcrop the more resistant layers strike W.N.W. and dip towards the S., but in the central part as well as towards its western end their strike is deflected towards the N. and the layers dip to the W.

Some differential thrusting accompanied by a greater deformation of the rocks is observable in the tectonic structure formed by the older strata to the E. and N.E. of these places. This is clearly visible in the uppermost stretch of the valley near the northern prolongation of the swamp of the Ciénega del Medio where, in addition to the dark greywackés, the greenish-coloured and purplish-red phyllitic slates are also exposed.

In the S. and W. borders of the outcrop the tillite dips towards the S. and S.S.W. underneath greenish grey greywacké, brownish grey sandstone, and other strata referable to the series of light-coloured beds. In its southern border it is noticeable that the greywacké and sandstone beds, often with vertical dip and northern strike, rest unconformably on the tillite. The unconformity underneath these beds marks a tectonic junction formed by thrusting. This is shown by the disposition of the same beds over the tillite in the western border of the outcrop where we find, instead of a continuous series, fragments of strata of different constitution and of variable dip and strike.

These complications are not a local phenomenon because the same essential features are also observable as far down-stream as near Leoncito Encima. The magnitude of the movements is here proved by the alternation of sets of beds which not only belong to the groups of strata related to tillites, but also to the series of dark greywackés and slates older than the tillites of the Ciénega del Medio. Sets of thrust strata occur, high up in the slopes of both sides of the valley, even near Leoncito Encima, where they lie over the more inclined strata of their floor. In the other mountain ranges of the Sierra de Tontal and, more to the N., in the deep transverse valley of the San Juan River, the same thrust-structure formed by the different series of Palaeozoic strata is also observable. Thrust-sheets are again found in other regions of the Precordillera where, in addition to the strata of the older Palaeozoic series, the different Carboniferous and Permian beds characterized by tillites take part in their constitution. Such thrust-sheets are very well seen in the western flank of the Precordillera of Mendoza, i.e. the Sierra de Uspallata.

It can be deduced from this that the strongest movements must have occurred after the last Upper Palaeozoic glaciations. It is evident, however, that they are not Tertiary movements because over the graded thrust-structure lie, in the Sierra de Uspallata, the much less disturbed Triassic porphyrites and porphyries and, in other places, the Upper Triassic and Rhaetic plant-bearing sediments.

III. The Outcrops of Leoncito Encima.

For several reasons it is not possible to study the stratigraphical and tectonic relationships that exist between the Carboniferous beds of the Leoncito Encima outcrops and the other Palaeozoic strata of the mountain range. The outcrops of both the right and left sides of the valley are found isolated, emerging from beneath the fresh-water deposits and old alluvial cones of probably Pleistocene age. The contacts of these beds with the other Palaeozoic strata are almost entirely covered by the detritus of small lateral valleys which descend towards the principal water course following the general strike of the Palaeozoic beds.

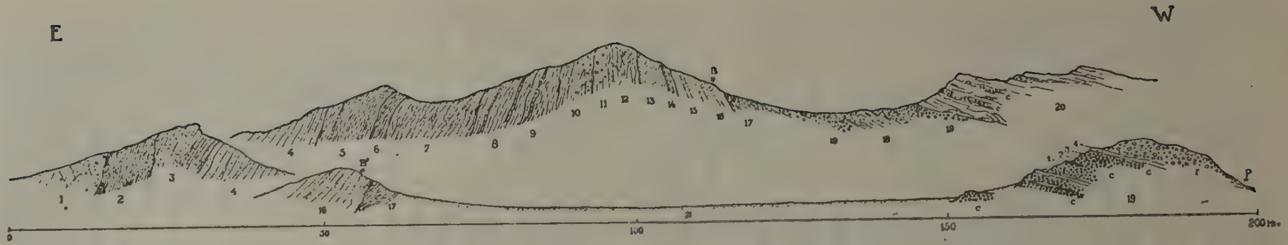
A single contact, however, is visible in a short stretch on the right side of the principal valley, where it is obviously of tectonic nature; fragments of light-coloured sandstone and dark grey slate of the Palaeozoic series which is exposed a short distance to the E. lie, thrust and without order, on less easterly inclined beds of greenish grey sandstone belonging to the group of Carboniferous strata which, in their turn, overlie layers of tillite. This short stretch is, thus, not useful for the purpose of explaining the stratigraphical and tectonic relations of the beds.

On the other hand, the uppermost beds of sandstones and conglomerates (No. 20 of the profile) in the eastern side of the outcrop of Leoncito disappear towards the E. underneath the old fresh-water deposits of the flank of the valley. There is, thus, no precise limit even in this direction.

The Carboniferous strata of these two outcrops, before they were dislocated by the last tectonic movements of the Palaeozoic, probably lay unconformably on older beds in the fashion of the tillite of the Ciénega del Medio. Owing to the dislocations present within the succession of the Carboniferous strata it is unlikely that the unconformity has been preserved and as the original floor of this group is not known, nothing can be said in this respect.

The transverse profile of Fig. 1 reproduces the succession which, among the other outcrops of glacial deposits of the valley of the Arroyo de las Cabeceras, is characterized by the presence of beds containing marine fossils and plant remains. It is difficult, when describing these rocks, to discriminate in a few words between sediments which have a similar appearance but are of different origin. This is especially the case with such rocks as those here called "greywacké" and "slaty greywacké" which are perhaps of marine or fresh-water origin or which have been derived from glacial deposits. It is also difficult to distinguish exactly the different types of tillites or to draw the line between such rocks as conglomeratic tillite and fluvio-glacial conglomerate as well as between a true tillite and a "sandstone" with widely dispersed pebbles.

Disregarding these difficulties and admitting the use of standard terms for the succinct description of the different groups of strata,



TEXT-FIG. 1.—Transverse profile of the Carboniferous beds on the left (South) side of the Valley of the Arroyo de las Cabeceras, by J. Keidel.

No. 1.—Dark olive grey greywacké-sandstone, confusedly stratified and weathering to a brownish colour. Rock shattered by joints, breaking up in small fragments, with widely dispersed, small pebbles of greywacké and milky quartz which are not striated but often flattened. The pebbles become somewhat more frequent near the junction with group No. 2. Strike N.N.W. 350°.; dip 60° E.

No. 2.—Thin layers of dark greenish grey, hard argillaceous slates, sometimes alternating with thin layers of light-coloured quartzitic sandstone. Rock partly laminated and crumpled (*Riebel*) by differential movements and resting with slight unconformity on the sandstone of group No. 3.

No. 3.—Fine-grained, whitish to yellowish grey micaceous sandstone. Some layers weather with dirty brown colour; others bear very fragmentary carbonized plant remains. The rock is often internally deformed and lies on group No. 4 with slight unconformity due to movements.

No. 4.—Fine-grained sandstone of light olive-grey colour, interbedded with more resistant layers.

No. 5.—Thin layers of dark grey argillaceous slate, partly arenaceous or somewhat phyllitic. Evident signs of lamination and crumpling (*Riebel*). This rock, seen from a distance, is very conspicuous by its general bluish hue.

No. 6.—Arenaceous slates and slaty sandstones of dark grey colour showing evident signs of crumpling due to differential movements within the group.

No. 7.—Compact sandstone, generally in thick layers, of yellowish to olive-grey and whitish grey colours, weathering with brownish hues. Fine-grained rock, partly shattered by movements within the group. Strike almost N. (N.W. 355°).

No. 8.—Thin layers of arenaceous slate and slaty sandstone of ashy grey colour, weathering with olive hue, with intercalated beds of grey to light grey, fine-grained sandstone. The slaty sandstones are finely banded in the planes of transverse rupture. Carbonized and very fragmentary plant remains.

No. 9.—Argillaceous greywacké-sandstone of dark olive-grey to brownish colour, partly schistose and very micaceous, with thin intercalated layers of micaceous sandstone bearing scarce and badly preserved plant remains. Within this group there is a layer of fine conglomerate with small pebbles of greywacké, milky quartz, etc. The beds of this group, more slaty in the western part of the outcrop, are warped and twisted.

No. 10.—Fine-grained greywacké-sandstone of dark grey to olive-grey colour. Rock shattered by joints, similar to that of group No. 1. It contains small scattered pebbles. Strike N.; dip 75° to 80° E.

No. 11.—Fine-grained, confusedly stratified, argillaceous sandstone of greenish grey colour, breaking up in small angular fragments.

No. 12.—Dark greenish to olive-grey greywacké sandstone, weathering with brownish hue. This rock contains scattered pebbles of greywacké, sandstone, and milky quartz up to 10 cm. in diameter, some of which are well striated.

No. 13.—Compact greywacké-sandstone of dark brownish grey colour. Rock similar to that of group No. 1, with small scattered pebbles.

No. 14.—Greenish grey micaceous-arenaceous slate with intercalated layers of very argillaceous sandstone of similar colour.

No. 15.—Argillaceous sandstone of greenish grey colour with thin layers of slaty sandstone.

No. 16.—Confusedly stratified layers of light grey sandstone with a slight greenish hue, partly argillaceous and of darker colour, partly calcareous. With nodules of calcareous sandstone and broken shells of brachiopods. The fossiliferous beds (*B*) are found in the western part of the group.

No. 17.—Blackish coloured mudstone, sometimes slaty by deformation, weathering with bluish, olive and yellowish grey hues and breaking up in small angular fragments.

No. 18.—Mudstone and argillaceous schist of blackish and dark grey colours intercalated, in some places, between the tillites of group No. 19. They enclose spherical and ellipsoidal concretions of hard argillaceous limestone of light and dark ashy grey colours.

No. 19.—Tillites, in part conglomeratic, of olive-grey colour, with boulders and pebbles of greywacké, different sandstones, sericitic mica-schist, limestones and dolomitic limestone (of Ordovician age), basic rocks, etc. Interbedded between the tillites there are layers of sandstone, slaty argillaceous sandstone, and argillaceous schists of greenish to bluish grey colours which yield plant remains. The group is rather variable in composition in the direction of the strike.

No. 20.—This thick group is only partially represented in the western extremity of the profile. It is formed by sandstone and grit of yellowish-brownish grey to greenish-ochre colours, always of light hues. The group contains layers of conglomerate formed by pebbles, some of which are striated, of the same composition as those of the tillites of group No. 19. This conglomerate has been considered as fluvio-glacial by du Toit (du Toit, A. L., 1927, 33). In several places the beds of this group are folded and separated from the tillites and other rocks of group No. 19 by a plane of tectonic movement.

No. 21.—Detritus and alluvial deposits of recent accumulation.

the profile of Fig. 1 shows that the succession of beds in the outcrop of Leoncito Encima is not entirely continuous and conformable. There are, on the contrary, lacunae due, in part, to differential movements between several of the groups of strata as well as between the strata forming the individual groups and, partly, to the change from accumulative to erosional activity of the ancient glaciers.

1. *The distribution of the fossils.*

The more frequent fossils are plant remains, although in the majority of instances these are very badly preserved.

Such remains are found in the beds that crop out to the E. of the brachiopod-bearing bed, as can be seen in the profile. The only determinable plant remains have been found, however, in the uppermost beds of the sandstones interbedded between the tillite layers in the rocky hillock which, in the N.W. end of the outcrop, rises up just by the hamlet of Leoncito Encima. The site is indicated by the letter P, on the right of the profile.

These remains have not yet been thoroughly studied, but according to a preliminary inspection, it seems that remains of *Rhacopteris* sp. occur among them. No forms have been found characteristic of the *Glossopteris* flora which, in several places in the Precordillera, are present in sediments associated with tillites of probably Lower Permian age.

Among the sediments of the outcrop of Leoncito Encima those of continental character appear to predominate, as plant remains are also found with the brachiopods and pelecypods, especially in the upper part of the grey to greenish grey sandstone beds (B), indicating the proximity of the ancient shore. Here the brachiopods, represented by a few forms, are the most frequent remains (B).

The principal fossiliferous locality, discovered in 1914, is the one marked B′ on the hillock in the foreground of the profile, where the fossiliferous beds, exposed in the lower part of group No. 16, dip towards the E. Another site lies a short distance to the S.S.W., where the fossils are also comparatively abundant. The remains become more and more scarce as we approach the line of the principal profile where the fossiliferous beds dip towards the W. The distribution of the fossils is, thus, irregular, but they have been found exclusively in the above mentioned assemblage of beds.

2. *The original succession of the Carboniferous strata.*

As a consequence of the last and very strong movements of the Palaeozoic Era, the original disposition of all the Palaeozoic strata, as well as their mutual relations, has been greatly altered in many regions of the Precordillera. This has often led to inversion of the strata and the tectonic suppression of part of them. Such complications may exist in all those places where signs of greater dislocations are observed. For example, inversion of the Carboniferous strata could occur where they crop out on both sides of the valley of the Arroyo de las Cabeceras near Leoncito Encima, as here part of the beds have undoubtedly been suppressed, especially along the limiting planes of different groups. An appreciable part of the outcrop is formed by the tillites and the interbedded and associated sediments, marked in the profile with the numbers 18 and 19. This is the group which, in the line of the principal profile, is separated from the brachiopod bearing sandstone (16) by a blackish mudstone (17).

Fortunately this group, the principal one of glacial deposits, furnishes us with the means of recognizing the original succession of strata within the group itself and even, perhaps, that of the beds of its floor. This follows from the existence, in the S.E. point of the hillock of tillites shown in the right foreground of the profile, of four striated and polished surfaces, marked with the numbers 1 to 4.

Two of these, numbers 2 and 4, coincide with the upper planes of sandstone layers interbedded between the tillites while the other two, numbers 1 and 3, are " boulder pavements ". The remnants of these striated, polished, and partly " moutonnées " surfaces are seen emerging from within an assemblage of tillite and sandstone 4 to 5 m. thick. Du Toit (1927, p. 34) had already referred to these as " some particularly fine boulder pavements ". (See Pl. VI.)

These polished surfaces are not inverted and each one of them, with the superposed layer of tillite, indicates a retreat and a new advance of the old glaciers and, accordingly, a stratigraphical break.

These breaks must be of some magnitude since plant remains are found in all the sandstones interbedded between the tillite layers, indicating a considerable change in the environment.

The group of glacial deposits and the beds of its floor are, nevertheless, still in the original order of sedimentation, as is shown by their common inclination. The brachiopod-bearing sandstone of group No. 16 is, thus, older than the tillites and plant-bearing sandstone of group No. 19, including the other sediments belonging to this group, marked with the number 18.

It cannot be deduced from this, however, that the strata exposed in the eastern part of the outcrop represent lower beds of the same Carboniferous series.

3. *The distribution of the glacial deposits in the succession of the Carboniferous strata.*

In several regions of the Precordillera, as for instance in the Quebrada de Uspallata and the western flank of the Cerro Pelado (Quebrada de los Manantiales) in Mendoza, we find series of strata of different composition and age several hundreds of metres thick, the lower part of which is formed by glacial deposits with intercalated sediments.

In these well defined groups there is a great number of tillites and fluvio-glacial conglomerates with intercalations of greywacké-sandstone with scattered pebbles, other sandstones and slates.

There is no doubt that in such outcrops we are dealing with a succession of deposits representing a single group of strata belonging to the Carboniferous as well as to the Lower Permian. In some places beds with marine fossils or with plant remains are also found in them.

The assemblage of Carboniferous beds of the outcrops of Leoncito Encima does not differ essentially from such groups.

Disregarding the sandstones and conglomerates of group No. 20 which are separated from the tillites of group No. 19 by a tectonic plane, the strata reproduced in the profile of Fig. 1 are rather less thick than the assemblages of glacial deposits and intercalated sediments that we find as has already been shown, in other regions of the Precordillera.

Tillites with many boulders and striated pebbles are found only in group No. 19. Deposits of similar character do not exist at lower horizons, although pebbles, some of them striated and of moderate size, are found in the greywacké-sandstone of group No. 12, but it is not possible to consider this rock as a tillite, owing to the wide dispersion of the pebbles. Nevertheless it is a sediment derived, at least in part, from glacial deposits and we can conclude that at the time of its formation glaciers existed in the neighbourhood.

It is permissible to infer, then, that before the deposition of the marine sediments with brachiopods of group No. 16, one of the climatic changes indicated by the tillites present in at least three series of newer Palaeozoic strata of the Precordillera of San Juan and Mendoza had already taken place.

It would also appear that the sediments of groups No. 1, 10, and 13 are related to glacial deposits. The rocks of these groups are greywackés very similar one to another, or even identical.

This greywacké closely resembles the matrix of the tillite (t) of group No. 19 which overlies the plant-bearing sandstone (P). Furthermore pebbles, although small and very scattered, are found in the rock of the three mentioned groups. It is, therefore, permissible to suppose that glaciers existed in the same region at the time of the deposition of these sediments.

If this interpretation of the origin of the above mentioned rocks is correct, the strata of the outcrops of Leoncito Encima would belong to a single succession of beds, whose age would be indicated by the brachiopods of group No. 16. This succession of strata which, according to the study of the brachiopods made by one of us can be referred to the Lower Carboniferous, cannot, however, be continuous, as tectonic unconformities are observed within the same.

4. *Signs of tectonic movements within the succession of the Carboniferous strata.*

The disposition of the strata cropping out on the right side of the valley differs from that of those strata on the left side.

In the outcrop of the right side, the tillites and other sediments corresponding to those of group No. 19 are not succeeded by the brownish grey sandstones and conglomerates of group No. 20, as in the outcrop of the left side. They are, instead, tectonically contiguous with the Palaeozoic beds exposed in the upper section of the valley. This is seen in the short stretch where thrust fragments of sandstone and slate, belonging to the series of the upper section of the valley, lie unconformably and without order on a sandstone stratigraphically related to a tillite bed.

In the left side of the valley, on the other hand, these strata must be in tectonic contact with the sandstone of group No. 1, the lowermost of the profile. This can be gathered from the proximity of the respective outcrops, although the actual contact is covered by the detritus of a small lateral valley.

Group No. 20 has a considerable thickness, although it is not possible to measure it exactly as it disappears, towards the W., underneath the Pleistocence fresh-water deposits. It is absent on the right side of the valley, but on the left side it overlies the tillites and other sediments of group No. 19 with a tectonic unconformity.

Underneath the tectonic plane the thickness of the tillites and other sediments of group No. 19 notably diminishes, towards the S.E., in the direction of the strike, as can be seen when comparing the principal profile with that in the foreground.

If the sandstones and conglomerates of group No. 20 formed part of the assemblage of Carboniferous strata lying on those of group No. 19 without an appreciable break, their absence over the tillite on the right side of the valley would indicate tectonic movements of great magnitude. It is doubtful, however, whether the sandstones and conglomerates of group No. 20, of a general brownish grey to light yellowish colour, form part of the succession of Carboniferous strata exposed in the outcrops of Leoncito Encima. It is almost certain that, instead, they are stratigraphically related to the series of light-coloured beds which, down-stream from Leoncito Encima, emerge, in scattered outcrops, from beneath the fresh-water and old alluvial deposits of the right side of the valley. This assemblage of strata differs strikingly, particularly by its light yellowish and greenish hues, from the Carboniferous strata of the outcrops of Leoncito Encima. They could form, therefore, another succession of strata younger than the Carboniferous one represented, in the profile of the outcrop of the left side of the valley, by groups No. 1 to 19.

The presence, among the sandstones in group No. 20, of layers of conglomerate with striated pebbles, considered by du Toit as fluvio-glacial deposits, does not contradict this supposition because at least in two places down stream from Leoncito Encima true tillites, of partly brownish green colour, are related to the yellowish sandstones and greenish slates. In these places we are dealing with glacial deposits the age of which can not be compared with the tillites of Leoncito Encima.

We could, perhaps, compare this assemblage of sandstones, slates, and tillites with the succession of yellowish grey and ochre-grey sandstones and greenish slates which, to the S.S.W. of the city of San Juan, crop out in the western base of the Sierra Chica de Zonda. This succession includes, in its lower part, the tillite layers of the uppermost of the three "glacial zones" distinguished by du Toit in the outcrops of the Sierra Chica.

If this comparison were correct, the succession of strata which, near Leoncito Encima, seems to begin with the sandstones and conglomerates of group No. 20, would be of Lower Permian age and would correspond to the "Jejenes beds" as defined by Keidel (1922, p. 259).

IV. Description of the Fossils.

BRACHIOPODA.

Genus SYRINGOTHYRIS Winchell, 1863.

Syringothyris keideli sp. nov.

(Plate V, figs. 1 *a–d*; text-figs. 2, 3 *e–j*.)

A species belonging to the genus *Syringothyris* is the most abundant form in the collection, there being more than sixty specimens, twenty-eight of which are complete shells in very good state of preservation.

Dr. Keidel in 1922 observed that in external appearance some of the shells resemble *Spirifer alatus* Sow. and *Spirifer rugulatus* Kutorga. On grinding down the ventral beak of several specimens, however, a well-developed syrinx was revealed and thus no doubt remained as to their generic identification.

External characters.—Shell spiriferoid, large, transversely elongate. Length about half the width; in small specimens somewhat more. Greatest width along the hinge-line. Cardinal extremities acutely subrectangular.[1]

Cardinal area relatively low compared with other species of *Syringothyris*. Height of area from one half to one-third the length of the ventral valve and usually from one-fourth to one-fifth the length of the hinge-line, although in one specimen it is one-third and in other less than one-fifth of that length. Its surface is horizontally striated, with no traces of vertical striae, probably owing to indifferent preservation of the shelly matter.

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[1] The cardinal extremities are often rounded by erosion, as in the case of the holotype, figured in Pl. V, fig. 1.

The area is never flat and varies from slightly to strongly concave (Text-fig. 3 *e–j*). Concavity more pronounced near the ventral beak, while in the vicinity of the hinge-line the area is almost flat, though in some specimens the whole area is strongly concave. The flat portion in those specimens with increasing concavity slopes anteriorly from the plane of the valves at an average angle of 72 degrees.

Apical angle variable, between 125° and 140°, usually about 130°.

Delthyrium large, broadly triangular, higher than wide or as high as it is wide. Delthyrial angle between 25° and 55°.

Ventral valve flattened subpyramidal in shape.

Beak pointed, acute, always arched and sometimes strongly incurved, always rising above the plane of the area.

Mesial sinus deep, well defined, smooth, narrow at the beak and increasing evenly in width towards the anterior margin. The line along its bottom is evenly convex, and the sinus is produced anteriorly in a linguiform V-shaped process, rounded at the extremity; this process is not marked off by an abrupt bending of the sinus.

In one specimen, the only one in which some parts of the outer layers of the shell have been preserved, it is possible to observe faint longitudinal rounded striae marking the surface of the sinus. These striae are much smaller than the plications of the lateral slopes.

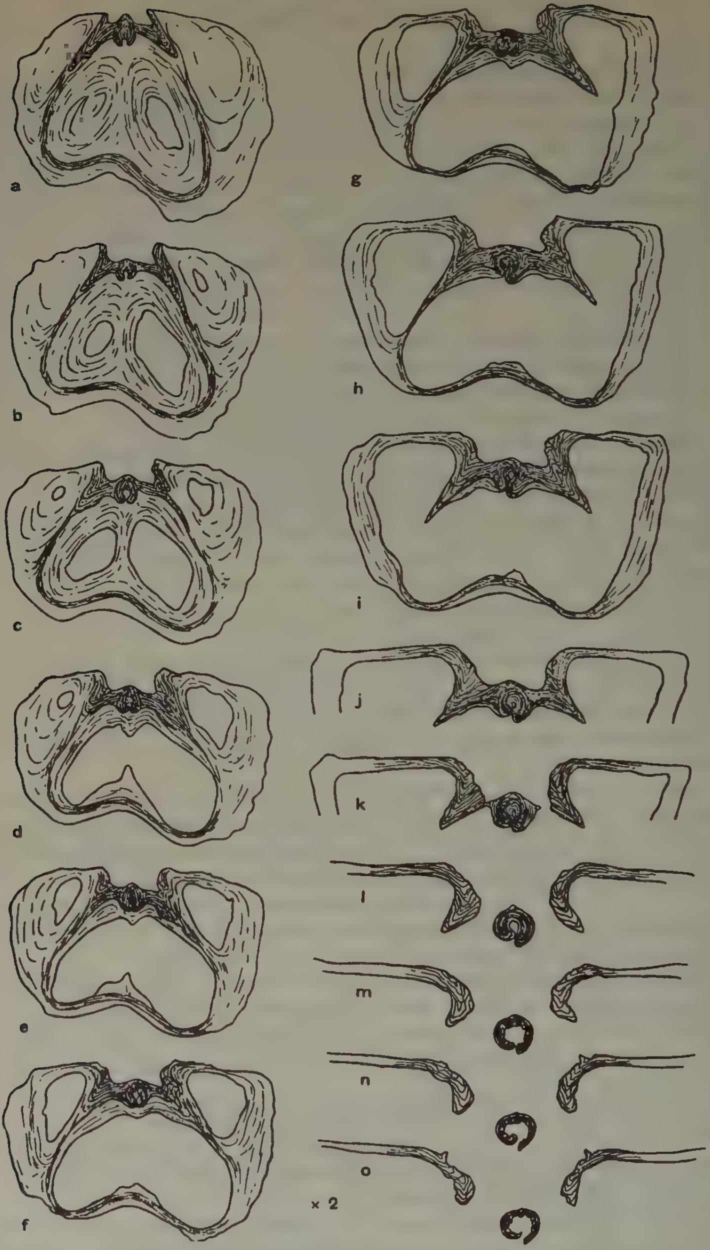
Lateral slopes usually convex, in a single instance slightly concave. The slopes on each side of the sinus marked by 18 or 20 rounded, simple and smooth plications, separated by shallow sulci and becoming obsolete towards the cardinal extremities.

Dorsal valve the more convex, sometimes globose. Beak strongly incurved, usually overhanging the base of the delthyrium. Dorsal area very small and low.

Mesial fold smooth save for a medial furrow that extends from the apex of the valve to the middle of the distance between the umbo and the anterior margin. Lateral slopes always convex, with 18 to 20 (or more ?) rounded, simple plications on each side of the fold.

Shell structure always punctate in "patchy" disposition of the punctures and showing the characteristic "twilled cloth" appearance of the shelly tissue. Concentric lines of growth present, especially near the anterior margin.

Internal characters.—Dental plates strong, much thickened by the apical callosity, very short, reaching the bottom of the ventral valve only in the umbonal region and extending along the bottom for one-fifth the distance between the apex and the anterior margin. Strongly diverging at an average angle of 70 degrees.



TEXT-FIG. 2.—Structure of the apical apparatus of *Syringothyris keideli* sp. nov. × 2. The dimensions of the specimen figured were: length of the hinge-line about 70 mm.; length of the ventral valve 30 mm.; height of the cardinal area 13 mm. Distance of sections from apex: (*a*) 1·7 mm., (*b*) 2·7 mm., (*c*) 3·5 mm., (*d*) 4 mm., (*e*) 5 mm., (*f*) 5·5 mm., (*g*) 6 mm., (*h*) 6·3 mm., (*i*) 6·7 mm., (*j*) 7 mm., (*k*) 7·1 mm., (*l*) 7·5 mm., (*m*) 8·5 mm., (*n*) 9·6 mm., (*o*) 10 mm.

Transverse plate strong, much thickened by deposition of shelly material, long and narrow, with a more or less well defined longitudinal median ridge on its outer surface ; it continues to connect the dental plates even after these no longer reach the bottom of the ventral valve. Its length is more than half the distance between the beak and the hinge-line.

The transverse plate swells along its longitudinal median line into a well developed syrinx or split-tube, open along its lower side.

Syrinx large, circular in section, continuing for a considerable distance after the transverse plate has disappeared, the length of this free portion being at least half that of the transverse plate. The syrinx dips from the apex towards the hinge-line with an inclination of about 23 degrees.

Ventral muscular impression large. In a specimen measuring 76 mm. along the hinge-line and more than 35 mm. in length, the muscle scar has a length of 14 mm. and a maximum width of about 13 mm.

The scar is visible between the dental plates, but as these are very short, it extends for more than two-thirds of its length beyond their extremities. It is oval in shape and both adductor and diductor impressions are well defined.

The two strong adductor scars form well-marked ridges converging towards the anterior part of the shell without, however, joining along the median line. They occupy less than one-half the length of the scar, being situated in the upper part of it.

The diductor scars consist of strong, deep striae, few in number (about 10 or 15 at each side), subparallel. Each set of striae diverges from the median line towards the anterior margin of the shell.

The pedicle muscle-attachments are not known.

Dimensions.—

	Holotype *		
Length of ventral valve . .	37·5mm.	40·5 mm.	43 mm.
Length of dorsal valve . .	32·5 ,,	35·5 ,,	33·5 ,,
Length of hinge-line . .	?72 ,,	?82 ,,	71 ,,
Height of area . . .	13 ,,	22·4 ,,	16 ,,
Width of delthyrium . .	17·5 ,,	20·5 ,,	15·5 ,,
Width of sinus . . .	?18 ,,	?23 ,,	20 ,,
Thickness	33·5 ,,	36 ,,	34 ,,
Apical angle	140°	135°	130°

* Figured on Plate V, fig. 1.

Affinities.—This species differs from *Syringothyris cuspidata* (Martin) and related forms by its greater apical angle and lower area, as well as by the strongly concave area and arched ventral beak, and the strongly diverging and short dental plates ; this last character also distinguishes it from most of the N. American species. It is comparable only with *Syringothyris texta* (Hall) from the Waverly group and the Keokuk Formation of the Mississippi

Valley Basin. *S. texta*, however, has a height often greater than the length (Hall, 1857, p. 169), while in our form the length is always from two to three times greater than the height. Furthermore, the area of *S. texta* is not so arched and the cardinal extremities end in more salient angles. But the principal differences are found in the structure of the apical apparatus, because the length of the transverse plate in *S. texta* is only one-third or less of the distance between the apex and the hinge-line and the free portion of the syrinx reaches just beyond half that distance, while in our form it almost reaches the hinge-line.

The apical apparatus of *Syringothyris solidirostris* Weller (1914), also from the Keokuk Formation, is comparable with that of our species, although the transverse plate is here longer and the free portion of the syrinx shorter than in our form.

Genus SPIRIFER Sowerby, 1815.

Subgenus Cyrtospirifer Nalivkin, 1918.

Spirifer (*Cyrtospirifer*) *leoncitensis* sp. nov.

(Plate V, figs. 2 and 3; text-figs. 3 *d*, 4.)

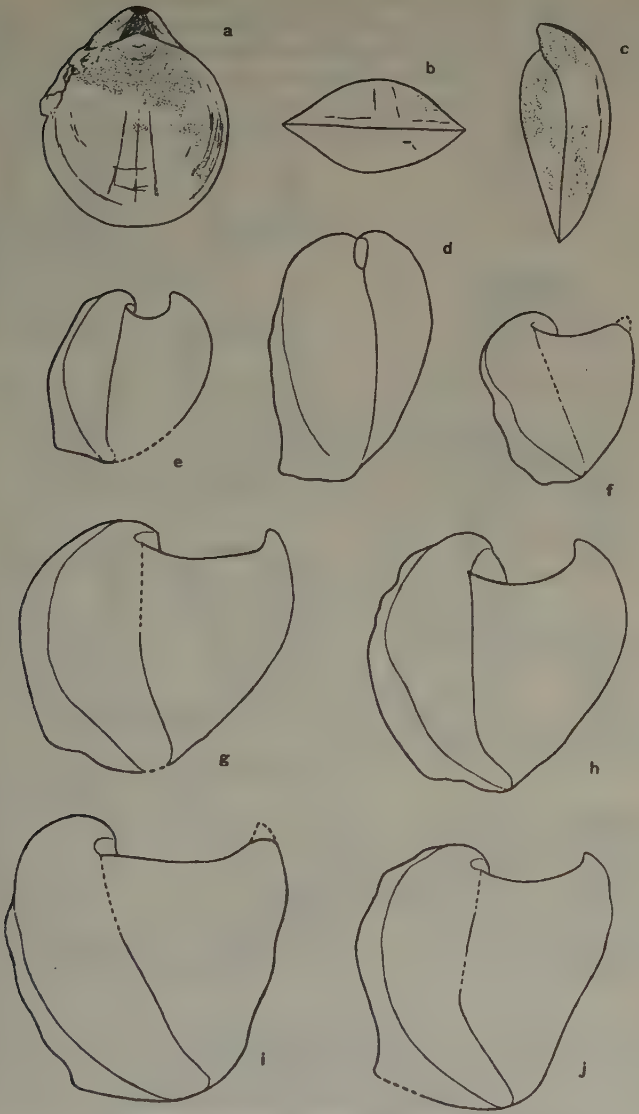
This species is represented in the collection by a number of detached valves and eight complete specimens.

External characters.—Shell spiriferoid, subelliptical in outline. Greatest width well below the hinge-line. Length of the hinge-line about four-fifths of the maximum width. Length of the valves subequal. Thickness about one-half the length and length about two-thirds of the greatest width. Height of cardinal area one-fifth the length of the hinge-line. Cardinal extremities rounded.

Ventral valve evenly and gently convex. Cardinal area low, triangular, small and well defined, occupying the whole of the hinge-line, almost parallel with the plane of the valves, flattened, arched only near the beak.

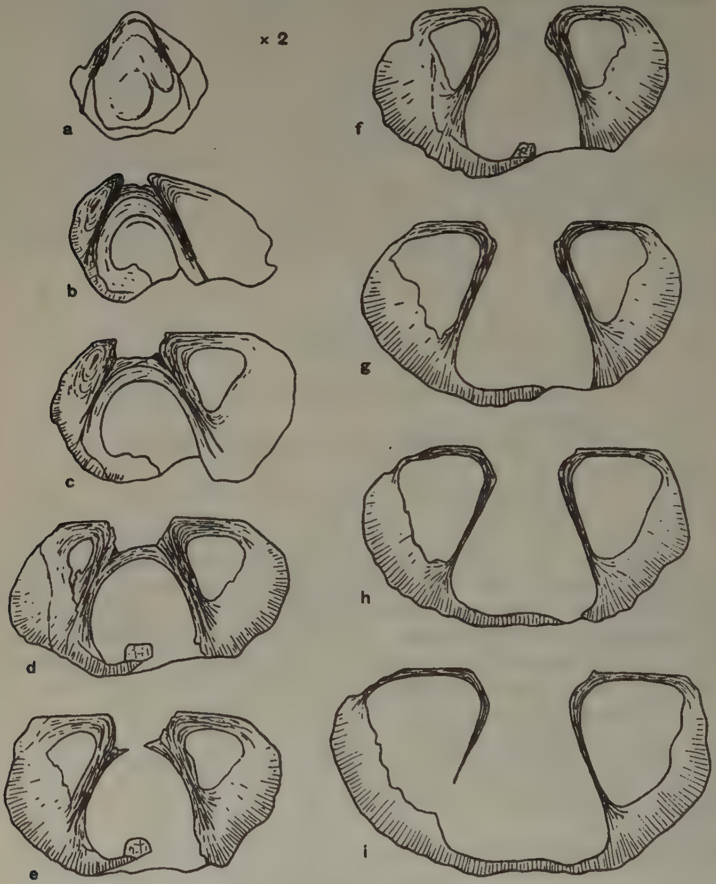
Beak pointed, incurved, overhanging the cardinal area and almost touching the dorsal beak.

Sinus narrow at umbo where it is almost indistinguishable from the rest of the valve, increasing in width rapidly towards the anterior margin where it is very broad and produced into a rounded linguiform extension. The lateral slopes as well as the sinus are covered by numerous rounded or somewhat flattish costae which bifurcate usually near the posterior margin. Sometimes, but rarely, the costae bifurcate again near the anterior margin. When the outer layers of the shell have been well preserved, the costae show a superimposed fine striation consisting of about seven to ten very fine and parallel lines on the surface of each costae.



TEXT-FIG. 3.—*a, b,* and *c* : dorsal, anterior and lateral views of *Dielasma* sp. cfr. *itaitubense* Derby. *d,* lateral view of *Spirifer* (*Cyrtospirifer*) *leoncitensis* sp. nov., figured in Plate V, fig. 3. *e, f, g, h, i,* and *j* : lateral views of several specimens of *Syringothyris keideli* sp. nov., showing variations of the cardinal area. Figure *h* is the holotype, figured in Plate V, fig. 1. All figures are natural size.

Dorsal valve the more convex in a transverse direction. Fold badly defined, almost impossible to distinguish from the lateral slopes. Dorsal area relatively high, almost as high as the ventral area and also closely following the plane of the valves. Beak pointed, slightly more globose than the ventral one, incurved and almost touching the opposite one, overhanging the area. Costae and striae as in the ventral valve. Lines of growth numerous in some specimens, especially near the anterior and lateral margins.



Text-fig. 4.—Structure of the apical apparatus of *Spirifer* (*Cyrtospirifer*) *leoncitensis* sp. nov. × 2. The dimensions of the specimen figured were: length of the hinge-line more than 24 mm.; length of the ventral valve more than 35 mm.; height of the area 8 mm. Distance of sections from apex: (*a*) 1·5 mm., (*b*) 2 mm., (*c*) 2·5 mm., (*d*) 3 mm., (*e*) 3·2 mm., (*f*) 3·3 mm., (*g*) 3·8 mm., (*h*) 4·5 mm., (*i*) 5·1 mm.

Internal characters.—Dental plates thin and short, reaching the bottom of the ventral valve only in the umbonal region, strongly diverging, more so than the boundaries of the sinus, with an average angle of about 45 degrees.

Transverse plate very short and strongly convex towards the exterior. Apical callosity well developed.

Dimensions.—

	(*a*)	(*b*)		
Length of ventral valve	34·5 mm.	29 mm.	35 mm.	38 mm.
Length of dorsal valve	32·5 ,,	28·5 ,,	—	—
Height of cardinal area	—	—	7 ,,	8 ,,
Width along the hinge-line	40 ,,	?34 ,,	?35 ,,	?42 ,,
Maximum width	51·2 ,,	42·5 ,,	45 ,,	—
Thickness	21 ,,	21·4 ,,	—	—

(*a*) Plate V, fig. 3. (*b*) Plate V, fig. 2.

Affinities.—The determination of the Argentine form as a member of the subgenus *Cyrtospirifer* Nalivkin is based on the presence of a transverse plate and on the plicated character of fold and sinus. Our specimens differ, however, from Nalivkin's diagnosis and from the genotype *Spirifer verneuilli* Murchison in having all the costae dichotomizing.

This character is, in my opinion, a secondary one and it can hardly be included in the diagnosis of a subgenus, especially considering that *S.* (*C.*) *verneuilli* and similar forms sometimes show bifurcations in the lateral ribs, as Nalivkin himself has pointed out.

In *Cyrtospirifer aperturatus* (Schloth) and *C. romanowski* Nalivkin, bifurcating lateral ribs occur very often and, in the first species, they even triplicate near the anterior margin. The bifurcation of the ribs on the fold and sinus is probably due to the greater development of these regions, enlarging the surface to be covered by the same number of costae.

In general shape, our shells resemble the specimens of *Spirifer wynnei* var. *saltensis* Reed, figured by Reed (1927, pl. xiv, fig. 7). These specimens were found by du Toit at Barreal, some 25 km. to the N.N.W. of Leoncito Encima. The similarity, however, is only superficial, as the costae bifurcate in a very different manner. Furthermore, Fredericks has pointed out (1926) that *S. wynnei* Waagen probably lacks both transverse and dental plates while possessing, instead, a well developed euseptoid structure.

Genus SPIRIFERINA d'Orbigny, 1847.

Subgenus Spiriferellina Fredericks, 1919.

Spiriferina (*Spiriferellina*) *octoplicata* Sowerby.

(Plate V, fig. 4.)

The subgenus *Spiriferellina* Fredericks is represented in the collection only by five imperfect valves, probably belonging to the same species, all of them rather badly preserved.

The best specimen, a detached ventral valve, has a breadth of 24 mm. and a length of about 17 mm. The beak is pointed and incurved and although the cardinal area is not visible it was, apparently, not very high. The preserved cardinal extremity is sub-acute, almost rectangular, the greatest width of the shell being at or just below the hinge-line.

All the specimens show a strongly punctate shell structure, but the punctae are small and visible only with a lens. In addition, each of the punctae seems to open at the top of a very small papilla, so that under a powerful lens and with oblique illumination, the entire surface has a somewhat rugose appearance.

This structure differs widely from that described by Waagen (1885) in the Indian specimens of *Spiriferina cristata* Schlotheim. This form shows a very coarsely punctate structure, "there being generally not more than four punctures to the space of one millimetre, so closely set that they nearly touch each other." In our specimens the punctures are much smaller, there being at least ten to the space of 1 mm., generally more, and widely separated from each other by distances that are equal to several times the diameter of any puncture.

The outer layers of the shell are missing, so this character is then shown by the inner layers.

The ventral valve is evenly convex but not globose.

The sculpture consists of four plications and a smaller and less distinct fifth near the cardinal extremities. The plications are angular and high, separated by angular and deep sulci. The mesial sinus only differs from the rest of the sulci by its greater size; there is not the slightest indication of a median ridge or elevation along its bottom.

The distance between the crests of the plications bordering the sinus is equal to the distance between one of these crests and the bottom of the second sulcus. The plications bordering the sinus are the strongest and they diminish in strength and size towards the cardinal extremities. The area between the fifth supplementary plication and the hinge-line is small and in the shape of an isosceles triangle. Only the first three plications on each side of the sinus originate at the beak, the other two rising from the hinge-line. The plications bordering the sinus are straight.

The imbricating lamellose structure of the shell has been preserved in two specimens only, the other being nearly smooth. The concentric imbricating lamellae are more regular and closer together near the anterior margin; towards the beak they become more irregular and spaced, but they are clearly visible throughout the shell. There are about six concentric lamellae in the space of 5 mm. near the anterior margin.

Remarks.—Our shells are very similar to the one figured by Davidson (1863, pl. vii, fig. 40), said to be taken from one of Sowerby's specimens, and to the description and figure by North

(1920, pl. xiii, fig. 9) of *Spiriferina octoplicata* mut. δ Vaughan. They also resemble very closely some forms of *S. campestris* White from Bolivia, figured by Kozlowski (1914, pl. xiv, figs. 17*b*, 18*b*). I have not been able, however, to detect in our form the characteristic spinules of *S. campestris* and, besides, the punctures of our specimens are much smaller than those present in the typical examples of this species.

It may be noted that Kozlowski considers Waagen's *S. cristata* Schloth. as identical with *S. campestris* (White) emend. Girty, in which case the coarsely punctate structure described by Waagen must be regarded as characteristic of *S. campestris*. But our specimens also differ from those figured by Kozlowski by their less incurved ventral beak and less convex ventral valve as well as by their cardinal extremities.

Genus DIELASMA King, 1859.

Dielasma sp. cfr. *Dielasma itaitubense* Derby.

(Text-figs. 3 *a–c*.)

The collection contains quite a number of shells belonging to the genus *Dielasma* King, but only a few of these are in a good state of preservation.

The entire shell is circular in outline and the dorsal valve is almost perfectly circular as can be seen by the figure and the measurements.

The ventral valve is evenly convex while the dorsal valve is more arched near the umbo and somewhat flattened in the anterior region.

Ventral beak slender, incurved and well separated from the dorsal apex, truncated by a medium size foramen.

Two ridges originate at the sides of the foramen and descend for a short distance towards the lateral portion of the ventral valve, thus marking off a triangular, rather high false area, more distinct near the ventral beak.

Anterior margin perfectly straight, without undulations or indentations.

On both valves there are a few central, radiating, badly defined shallow furrows that do not reach the anterior margin. The concentric lines of growth are faint, visible near the margins. Otherwise the shell is smooth.

Dental plates divergent, well developed. Septal ridges inconspicuous.

Shell structure punctate, the very small punctae visible only with a powerful lens.

Dimensions.—

	(*a*)		
Length of ventral valve . .	29·5 mm.	31 mm.	38·5 mm.
Length of dorsal valve . .	26 ,,	?26·5 ,,	35·5 ,,
Width of the shell . . .	25·5 ,,	27·5 ,,	34 ,,
Thickness	12·5 ,,	13 ,,	18·5 ,,

(*a*) Specimen figured in Text-fig. 3.

Remarks.—The principal characters of this form are the perfectly straight margin, the circular outline of the shell and the carinated beak marking off a more or less well-defined false area.

Judging by the straight character of the margin, the present form could be considered as a member of the *D. hastata* group of Waagen (1885), but the species related to *D. hastata* Sow. are generally elongate or subpentagonal in outline and do not possess the peculiar carinated beak.

Probably our specimens are best compared with *D. itaitubense* Derby (1874) from the Upper Carboniferous of Brazil. Here the carinated character of the ventral beak is strongly developed and, furthermore, this species has an anterior margin very slightly arched or nearly straight and both valves are considerably flattened near the anterior region producing a sharp and wedge-like margin.

Derby's species is more elongate than the present form, but Waagen (1885, p. 348) has described a *D. itaitubense* from the Productus Limestone that is less elongate than the Brazilian specimens, remarking that he did not feel justified in considering the Indian form as a new species on the strength of that character alone.

The form now under consideration is even broader than the Indian one, being almost circular in outline, but the individual and zonal variations of the species of *Dielasma* are so considerable that it does not seem justiable to draw any conclusions from that fact.

Furthermore, Derby has himself figured (1874, pl. 2, fig. 8) the internal cast of a dorsal valve almost perfectly circular and he gives the measurements of a ventral valve as: length, 32 mm.; width, 32 mm.; saying that, "the last is an unusually short and broad ventral valve."

Probably our form cannot be directly assigned to *D. itaitubense* but it possibly represents an earlier and simpler form closely related to that species.

Genus BEECHERIA Hall and Clarke, 1895.

Beecheria cfr. *sublaevis* Waagen.

A single specimen, rather well preserved, seems to belong to the genus *Beecheria* Hall and Clarke.

It is a fairly small shell, ovoid in outline, with strongly inflated dorsal valve. The ventral valve is somewhat flattened transversally, but vaulted in the longitudinal sense. The ventral beak is broken and the size of the foramen is, thus, not known. The dorsal valve is very inflated, with a slender and pointed beak. Both valves are smooth, save for numerous fine and crowded lines of growth. Front margin vaulted but without the slightest indentation. Punctate structure of the shell very fine, visible only by means of a powerful lens. Dental plates absent.

Dimensions.—

Length of ventral valve . .	12·5 mm.
Length of dorsal valve . .	11 ,,
Maximum width . . .	13·8 ,,
Thickness	9·5 ,,

Remarks.—The specimen described above closely resembles some of the *Beecheria* ("*Hemiptychina*") *sublaevis* figured by Waagen (1885, pl. iv, fig. 1) from the Productus Limestone, as well as the shell figured by Reed (1927, pl. xiii, fig. 5) as *Hemiptychina* cfr. *sublaevis* from Barreal.

INDETERMINABLE SPECIES.

Spirifer sp. indet.

There is one small fragment of a ventral valve showing only the umbonal region, certainly different from the species already described. It resembles *Spirifer barrealensis* Reed from Barreal, especially by its peculiar sculpture, and also *Spirifer* aff. *rajah* Salter from the same locality (Reed, 1927, pl. xiv, figs. 2 and 5).

Reticularia sp. indet.

Two badly preserved specimens probably represent the genus *Reticularia* McCoy. The sculpture consists of small pustules disposed in concentric rows and at the same time in radial lines. Exfoliation greatly obscures the details of the structure, but some of the pustules resemble the "twin pore" spine-bases of *Phricodothyris* George (1932, p. 528) for the insertion of the "double-barrelled" spines.

They might equally well, however, represent the split nodes of the type described by George in *Reticularia imbricata* Sow. and *R. profecta* George.

The outline of the specimens has not been preserved and the strongly convex valves are too imperfect to enable further conclusions.

Orthidae gen. indet.

Two badly preserved dorsal valves probably represent some genus of the family Orthidae. The general appearance of the valves resembles that of *Schizophoria resupinata* Martin as figured by Davidson (1863, pl. xxx, fig. 1) and *Schizophoria swallovi* Hall as well as that of *Dalmanella subcarinata* Hall (Hall and Clarke, 1895).

LAMELLIBRANCHIA.

Naiadites sp. indet.

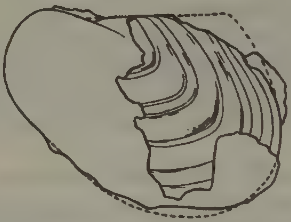
(Text-fig. 5.)

Among the pelecypod remains the chief form seems to be a species of the fresh-water and brackish water genus *Naiadites* Dawson (Davies and Trueman, 1927). The shell is moderately large, ovally subtriangular in outline. The umbonal region as well as the anterior region are badly preserved in all our specimens and the anterior end is, thus, not visible, but it was probably very small and almost obsolete.

Umbones obtuse and swollen.

The borders have not been preserved and in one specimen only is a portion of the posterior margin to be seen, but apparently the inferior and posterior borders are perfectly straight.

The posterior slope of the shell between the posterior border, the superior one, and the carina is concave in the left valve. The rest of the valve is convex, the greatest convexity being at the umbonal region.



TEXT-FIG. 5.—*Naiadites* sp. indet. Nat. size.

Inequality of the valves well marked; the right one is much flatter than the left.

Surface almost smooth and covered with fine striae and lines of growth. Near the borders, especially near the anterior one, the lines of growth are closely set and more distinct.

These specimens are very similar to the figures given by Hind (1896, pl. xix, fig. 19) of *Naiadites magna* Hind from the Lower Carboniferous limestone of Scotland, but differ from this species by their straight inferior margin and posterior borders. They also resemble *N. obesa* Etheridge Jr., as figured by Hind.

Dimensions.—

Length	36	mm.
Height	25·5	,,
Thickness	12	,,
Supero-carinal angle . .	39	
Supero-posterior angle . .	125	

The following forms have been identified in the collection made by Dr. Keidel at Leoncito Encima :—

Syringothyris keideli sp. nov.
Spirifer (*Cyrtospirifer*) *leoncitensis* sp. nov.
Spiriferina (*Spiriferellina*) *octoplicata* Sow.
Dielasma sp., cfr. *itaitubense* Derby.
Beecheria cfr. *sublaevis* Waagen.
Spirifer sp. indet.
Reticularia sp. indet.
Orthoid, gen. indet.
Naiadites sp. indet.

Of the twenty-four or twenty-five of *Syringothyris* which have been described hitherto from Europe, N. America, N. Africa, Australia, India, Persia, and Japan, only two have been found in rocks younger than Lower Carboniferous. All the others are limited to the Lower Carboniferous strata.

The two exceptions, *Syringothyris cuspidata* var. *lydekkeri* Diener and *S. nagmargensis* Bion, have been found in Kashmir, the first one in the *Fenestella* shales and the lower part of the Agglomeratic Slate series, the second in the upper beds of the last-named series.

Bion (1928) and Reed (1932) have considered these species as of respectively Moscovian and Uralian age. These two species, however, in no way resemble the Argentine form which seems, instead, to be closely related to *S. texta* Hall from the N. American Mississippian.

Cyrtospirifer has, hitherto, only been recorded with certainty from Middle and Upper Devonian rocks. It is impossible to retain in this subgenus the Permian *Spirifer rugulatus* Kutorga and the Upper Carboniferous *Spirifer tastubensis* Tscher., as Fredericks (1926) proposes. The former species cannot be regarded as a *Cyrtospirifer* since it possesses smooth fold and sinus. This is also the case with "*Cyrtospirifer*" *kharaulakhensis* Fredericks from the Kharaulakh Mountains.

The inclusion of *S. tastubensis* in this subgenus is also very questionable, and judging by its *Syringothyris*-like appearance it would be better considered as a species of *Cyrtella* Fredericks or *Pseudo-syrinx* Weller.

The presence of the Devonian species *Cyrtospirifer dubius* Etheridge Sr. in the Permian rocks of the Kharaulakh Mountains, is also rather doubtful.[1]

Cyrtospirifer leoncitensis sp. nov. does not resemble any of the six or seven unquestionable species of the subgenus known until now.

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[1] *Cyrtospirifer dubius* was described many years ago from the Devonian rocks of Queensland (Etheridge, R., 1872, p. 330). Fredericks has identified this species among the fossil remains collected by Vollossovitch in the Kharaulakh Mountains, all of which he considered as of Permian age. As the fossils were collected, however, from different parts of the mountains and their stratigraphical position is not given, it is possible that they belong to several horizons of different age.

On the strength of these two forms, *Syringothyris keideli* sp. nov. and *Spirifer* (*Cyrtospirifer*) *leoncitensis* sp. nov., and the additional evidence afforded by the presence of *Spiriferina* (*Spiriferellina*) *octoplicata* Sow., it seems to me fairly safe to regard this marine fossiliferous bed of Leoncito Encima as of Lower Carboniferous age.

Dielasma itaitubense and *Beecheria sublaevis* are known from Lower Permian and Upper Carboniferous strata, but it is possible that both species are long-lived forms, like many of the Palaeozoic Terebratulids, and that they also might occur in Lower Carboniferous rocks. Furthermore, the identification of both these species in the present collection is rather doubtful.

These conclusions as regards the age of the brachiopod-bearing bed are confirmed by the very probable presence of *Rhacopteris* remains in the uppermost of the layers of sandstone interbedded between the tillites which overlie the marine sediments.

V. Summary and Conclusion.

In the valley of the Arroyo de las Cabeceras, three different Upper Palaeozoic series seem to crop out in scattered exposures.

The lower series, formed by dark greywackés and slates, is separated by a primary unconformity from the succeeding one. The age of these rocks is still unknown, but according to Bodenbender and Stappenbeck they should be considered as marine Devonian sediments.

The second series is especially interesting because it contains several glacial horizons, a marine fossiliferous bed with brachiopods and lamellibranches and another bed with determinable plant remains. The Lower Carboniferous age of this series is proved by the study of the marine fossils and confirmed by the very probable presence of *Rhacopteris* sp. among the plant remains.

A third and younger series, mainly formed by light-coloured sandstones and greywackés, is also partly of glacial origin. Perhaps it is possible to compare it with the " Jejenes beds " of the " La Rioja system " of Keidel, considering it as of Lower Permian age.

Before the sedimentation of the Lower Carboniferous series, tectonic movements are shown to have taken place. The strongest foldings and thrustings occurred, however, after the deposition of the series of light-coloured beds and before the sedimentation of the Upper Triassic and Rhaetic plant-bearing beds present in other regions of the Precordillera.

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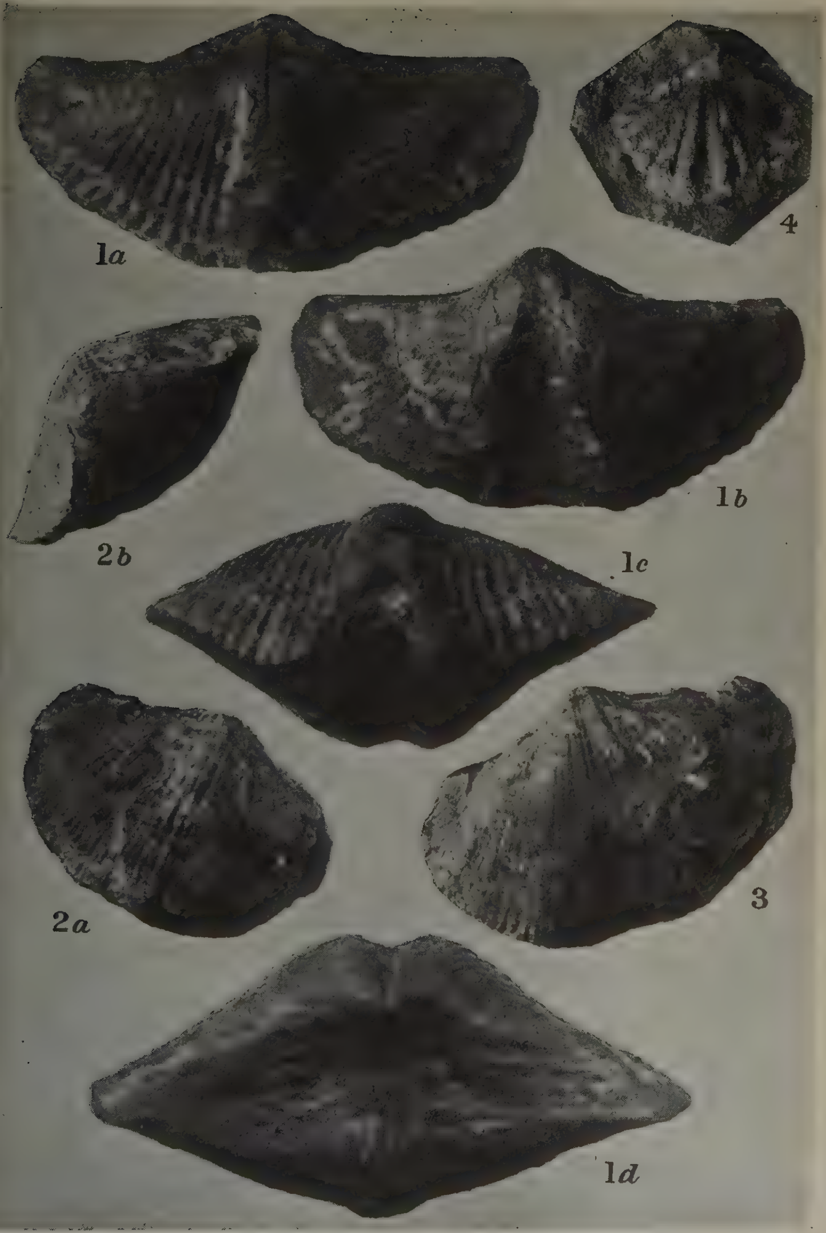
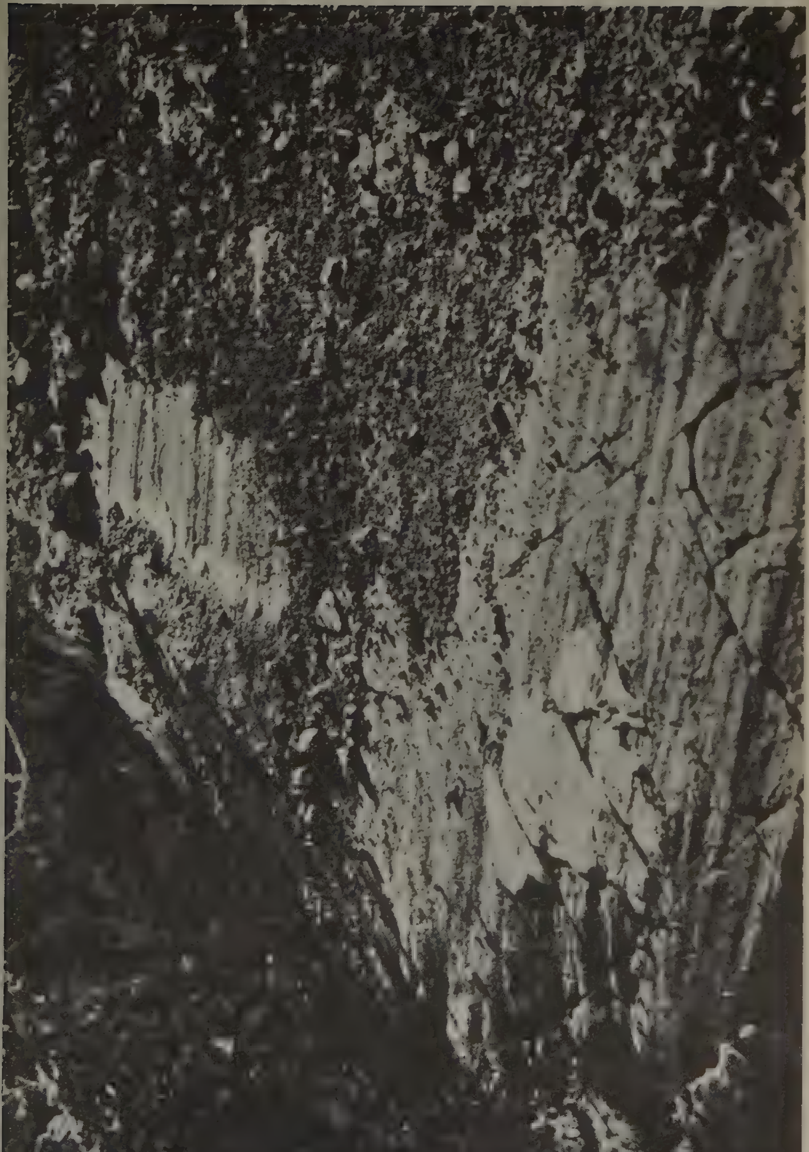


Carboniferous Brachiopods from W. Argentina.

[To face p. 128.



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EXPLANATION OF PLATE V.

Fig.

1. *Syringothyris keideli* sp. nov. (*a*) dorsal view, (*b*) ventral view, (*c*) anterior view, (*d*) posterior view.
2. *Spirifer* (*Cyrtospirifer*) *leoncitensis* sp. nov. (*a*) dorsal view, (*b*) anterior view.
3. *Spirifer* (*Cyrtospirifer*) *leoncitensis* sp. nov. Ventral view of another specimen.
4. *Spiriferina* (*Spiriferellina*) *octoplicata* Sow. Detached ventral valve.

All the figures are natural size.

EXPLANATION OF PLATE VI.

Polished and striated surface of a layer of sandstone marked with the number 2 in the western extremity of the profile of Text-fig. 1. The exposure is some 2·5 to 3 m. wide in the direction of the photograph.

Photograph taken from the W.S.W., obliquely to the strike which is somewhat variable, around N.W. 350°.

Mineral Orientation in Some Olivine-rich Rocks from Rum and Skye

By F. C. Phillips, Department of Mineralogy and Petrology, University of Cambridge.

THE olivine-rich rocks have acquired a particular significance in petrogenetic discussions as a result of the growth of the realization of the difficulties involved in postulating the existence of anhydrous melts of corresponding composition. The belief that such rocks have originated through the local accumulation of olivine crystals, without significant remelting (Bowen, 2, p. 108; 3, pp. 133–174)[1] has received added support from the experimental determination of the melting relationships of the olivines. The facts "seem susceptible of no other interpretation than that, when such masses become rich in olivine, they do so through the accumulation of crystals of that mineral, which remain as such and do not become a part of the liquid by remelting or re-solution" (4, pp. 394–5).

When such rocks are found as intrusions they must therefore have been emplaced as a largely crystalline mass from which the interstitial liquid was eventually more or less completely expressed. It is to be expected that such rocks should show evidence of deformation, and Bowen has drawn attention to the significance from this point of view of the fissility frequently developed in dunites and allied rocks in the Hebridean province (3, p. 156; 4, p. 395). Of the ultrabasic intrusions in the Isle of Rum, all the olivine-rocks "have a fissile structure in some measure" (Harker, 9, p. 87), whilst the allivalites, also, "have a very decided tendency to parallel alignment of the crystals of felspar, and to some extent of the olivine" (9, p. 90), and it is abundantly clear from the original descriptions that these features are primary and are in no way due to later movements. It therefore seems of interest to make quantitative measurements of the fabric of some of these rocks by means of the universal stage.

Olivine being orthorhombic, its crystallographic orientation is of course most readily fixed by locating the three principal optic directions, α, β, and γ. Measurement of a hundred crystals in each slice suffices to give a clear representation of any preferred orientation which may be present. In Text-figs. 1 and 2 are plotted 100α and 100γ from a fissile dunite from the head of Glen Harris, Rum, and these results are typical of the more olivine-rich rocks with pronounced fissility. The plane of fissility runs left and right in these figures, normal to the plane of the figure, and it is readily seen that there is a marked preferred orientation, with α (crystallographic y) normal to the plane of fissility. The orientation of the crystals *in* this plane is not so marked, the poles of γ lying in a girdle (Text-fig. 2). To some extent this lattice-orientation involves also a dimensional orientation. Many of the crystals are equidimensional, but in others the elongation in the plane of fissility may be seven or eight times the width normal to this plane. The *average* length, measured by means of a micrometer stage over a

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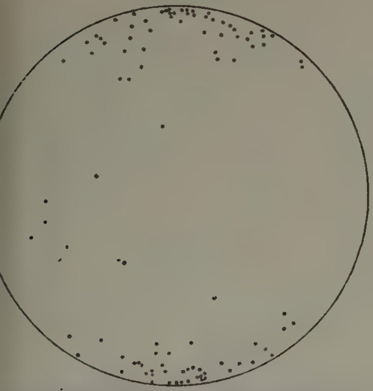
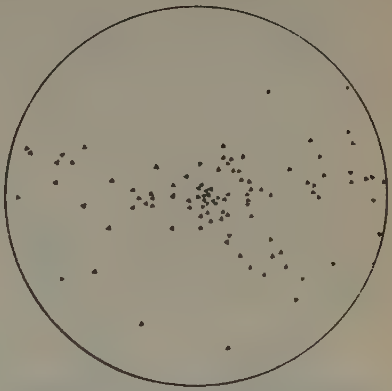
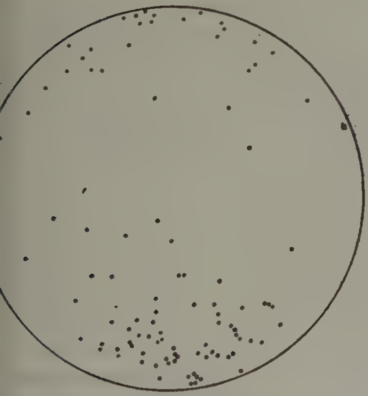
[1] Figures in parentheses refer to References at end of article.



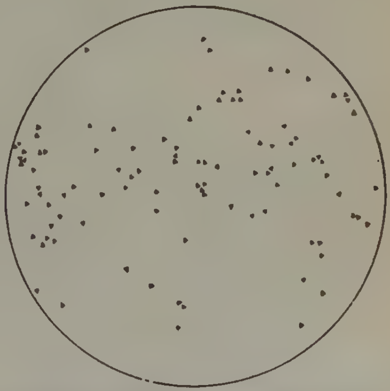
xt-fig. 1.—Dunite in the escarpment the head of Glen Harris, Rum. 100α.



Text-fig. 2.—100γ from the same slice as Text-fig. 1.



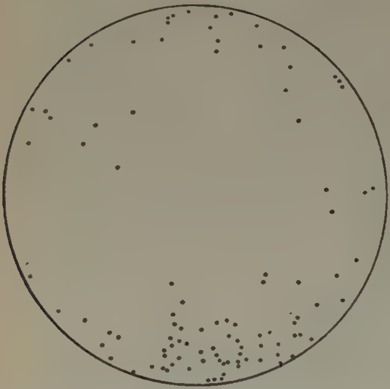
t-fig. 3.—Allivalite near Barkeval Pass, Rum. 100α.



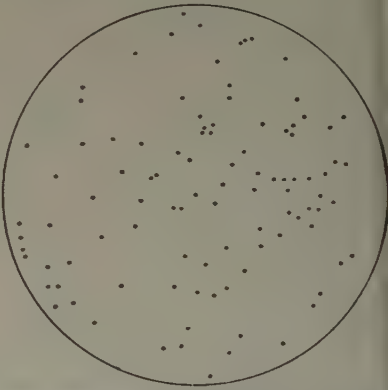
Text-fig. 4.—100γ from the same slice as Text-fig. 3.

few hundred grains, was found to be 0·9 mm., whilst the average width is 0·6 mm.

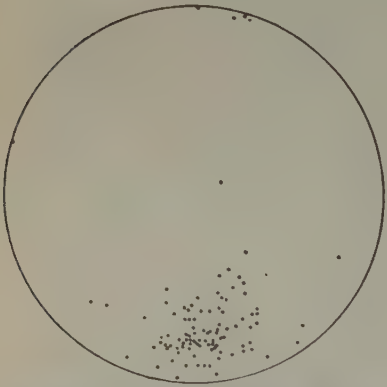
In rocks less rich in olivine, the arrangement is similar but less perfectly developed. In Text-fig. 3 are plotted 100α in an allivalite from near Barkeval Pass, Rum, and in Text-fig. 4 the corresponding measurements of γ. The fissility of such a rock depends largely on the arrangement of the plagioclase (An_{85}), which lies with its 010 cleavage fairly sharply orientated (Text-fig. 5).



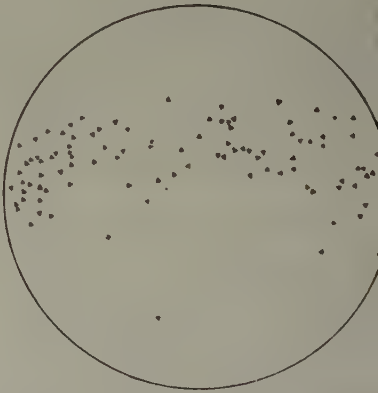
Text-fig. 5.—Normals to 010 in plagioclase of same slice as Text-fig. 3.



Text-fig. 6.—Black olivine-rock, south
Abhuinn Fiadh-innis, Rum. 100*a*.



Text-fig. 7.—Dunite from dyke on southern slope of the western ridge of Sgùrr Dearg, Syke. 100*a*.



Text-fig. 8.—100γ from the same slice
Text-fig. 7.

A marked fissility is a noticeable feature also in some of the later peridotites of Skye. In a dyke on the ridge of Sgùrr na Banachdich "a tendency to parallel orientation of the crystals . . . gives rise to a rough platy fracture"; again, an intrusion on Soay "has a certain parallel orientation of its crystals which gives rise to a decided fissility" (8, p. 378). In Text-figs. 7 and 8 are plotted 100α and 100γ in a fissile dunite from a dyke on the southern slope of the western ridge of Sgùrr Dearg. This rock is probably from the same dyke as that described in some detail by Bowen (3, p. 156; "high up on the north wall of Coire Labain" brings one on the southern slope of Sgùrr Dearg). As in the rocks from Rum, there is a definite elongation of many of the olivine crystals parallel to the plane of fissility. The *average* dimensions were found to be 0·8 mm. parallel to this plane and 0·4 normal to it, but some individuals are of course of much more pronounced elongated habit. From Text-figs. 7 and 8 it will be seen that the constant feature of the fabric is α normal to the fissility. In any section normal to this plane, the slower vibration-direction is parallel to the long edges of the crystal, but this direction is not necessarily γ itself (3, p. 156). Traverses in two directions at right-angles across a slice cut parallel to the fissility gave average dimensions of 0·6 mm. and 0·7 mm. respectively.

A similar orientation, with α normal to the schistosity and γ occupying a girdle, has been found by Andreatta (1, 1 *a*) in olivine-rich rocks from the Ortles-Cevedale massif. These rocks occur as concordant lenticles in a gneissose formation in the mountain range between the Val d'Ultimo and the Val di Pescara. They are usually medium-grained, with fairly equidimensional crystals of olivine and a slight schistosity. From their concordance with the enclosing gneisses and from the distinctive characteristics of their fabric they are believed by Andreatta to be metamorphic rocks of deep-seated origin, for which reason he uses the term olivinite, by analogy with amphibolite, eclogite, etc., as metamorphic derivatives of the corresponding igneous rocks.

A similar fabric has likewise been found by Ernst (5, p. 149) in olivine-schists from Vanelven, Sunnmöre, Norway; and the same author shows it to be a characteristic feature of the olivine-nodules of basalts from many localities (5). Basing his evidence partly on the existence of this fabric, he has developed the conclusion that such nodules are not endogenous, but are fragments of older olivine-rocks which had been subjected to a period of orogenetic stress before being caught up by the igneous rock; the present aspect of some of these basalts is thus partly the result of processes of assimilation (5, p. 148; 6; 7).

As further evidence of the deformation suffered by these earlier olivine-rocks, Ernst cites the lamellar structure frequently developed in the olivines of the nodules, but not seen in the olivines of basalts and limburgites. This is regarded as due to translation, apparently on a plane approximately parallel to 100—"Ich fand, dass es sich in der Hauptsache um eine Fächerung um eine Richtung, die angenähert β entspricht, handelt" (5, p. 153). Such a lamellar structure is well developed in the olivines of the rocks from Rum and Skye, especially in some of the rocks which are particularly rich in olivine, and repeated measurements have shown that γ is always approximately normal to the plane of the lamellae. As a result of the distribution of γ in a girdle, these lamellae are seen in all sections of the Sgùrr Dearg rock cut normal to the plane of fissility; they are also clearly seen in a section parallel to this plane, though Ernst records the opposite statement of some of his slides of the nodules from basalts (5, foot of page 153). The same writer notes that the perfection of orientation of α decreases as the lamellar structure becomes more prominent, the concentration of poles tending to expand into a girdle; the same is true of the rocks examined from Rum. A black olivine-rock from the south of Abhuinn Fiadh-innis presents a remarkable development of lamellae; the crystals are of equidimensional habit (the *average* grain-size measured in two traverses at right angles proved to be 1·1 mm. in each case), but there is an extreme variation between the sizes of different crystals, a few reaching a diameter of 5 mm. Text-fig. 6 shows that there is scarcely any preferred orientation, and the fact that this rock also tends "to break up rather easily under the hammer" (9, p. 87) seems to be due almost entirely to the presence in it of the well-known variety of olivine with pronounced cleavage (9, p. 82).

It would therefore appear that the stresses acting during the emplacement of an olivine-rich intrusive already largely crystalline can develop in the rock precisely those features of the fabric which have been considered to indicate a metamorphic origin. The resemblance of these rocks from Rum and Skye to the nodules of basalts in texture, grain-size, orientated fabric, and prominent development of translation-lamellae is so close that these criteria at least suggest no need to look further afield for the source of such nodules than to an earlier phase of the same period of activity. Nor does the existence of this fabric in a concordant intrusion of peridotitic composition in a metamorphic series necessarily seem to imply that the intrusion is pre-metamorphic, though it may be related to the regional metamorphism, for, as Harker has pointed out "[Peridotites related to regional metamorphism] are for the most part indistinguishable from peridotites intruded under more ordinary conditions, a certain tendency to a parallel disposition of the crystal elements being common to both" (10, p. 305).

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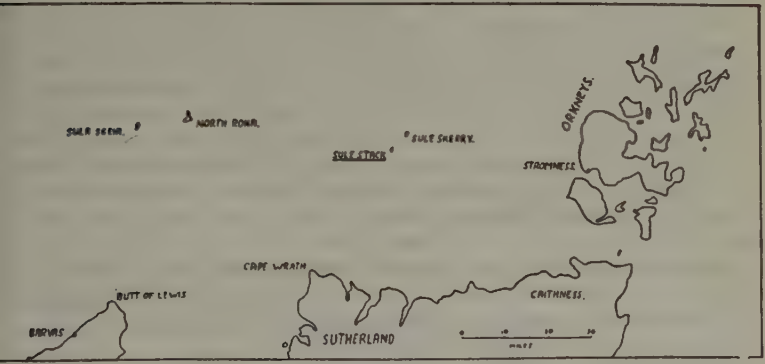
Notes on the Geology of Sule Stack, Orkney

By Malcolm Stewart.

The rock known as Sule Stack is situated in the North Atlantic Ocean in latitude 59° 2′ north and longitude 4° 30′ west. It is therefore some 35 miles north of the mainland of Sutherland and some 40 miles west-north-west of Stromness, in Orkney, to which latter point it is said to pertain. The nearest piece of land to Sule Stack is Sule Skerry, a low-lying reef with a lighthouse some 5 miles north-east. Both Sule Stack and Sule Skerry are situated on the 30-fathom Skerry Bank. Care should be taken not to confuse Sule Stack with the island of Sula Sgeir lying some 57 miles to the westward in latitude 59° 6′ north and longitude 6° 9′ west (6).[1]



Text-fig. 1.

Sule Stack is chiefly noted for its gannetry, the population of which has recently been estimated at about 3,500 breeding pairs (5). The name *Sule Stack* is derived from the Gaelic word *Sulaire*, a gannet (cf. *Sula bassana*), and *Stack*, a Scandinavian word denoting a pinnacle of rock whose height is considerable compared with its base area. *Stack* is the opposite of *Skerry*, a low lying reef of rock. Meaningless names such as *Stack-Skerry* and *Stack of Stack and Skerry* are therefore to be avoided.

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[1] Figures in parentheses denote list of references at end of paper.

Topographically Sule Stack is nothing more than a high rounded lump of gneiss, 120 to 130 feet in height and of perhaps 6 acres in area. It is entirely devoid of any form of vegetation, but covered with white guano. It is oval in shape and orientated approximately north-north-east and south-south-west, and is divided into two portions by a narrow gully. The northern portion is the higher as well as the larger of the two. It is this gully that makes landing so difficult, as the swell, which is always severe round Sule Stack, rushes through between the two portions of rock with the result that even on the east side there is little shelter. It was on account of this that the late Duchess of Bedford was prevented from landing in 1914 (1). With the exception of the west side which is precipitous, the whole rock is rounded so as to permit climbing in most places. Two general photographs of Sule Stack appear in the present writer's paper on this gannetry (5), and others have been published by the Duchess of Bedford (1).

In the early hours of 31st July, 1937, the steam yacht *Golden Eagle* left Loch Eriboll for Sule Stack. Though hazy, the weather was good and the swell slight. The writer was therefore lucky enough to be able to make a landing on the east side of the northern portion. It was probably a considerable time since anyone had landed, as the swell is usually too great. The late J. A. Harvie-Brown, who considered Sule Stack to be " certainly one of the most inaccessible of all our Scottish islets ", made three unsuccessful attempts to land in July, 1887, on 29th June, 1889, and on a further occasion (2, 3). Professor Newton and Mr. H. Evans did not land on 28th June, 1890 (3), and the Duchess of Bedford, who paid three visits on 17th May, 19th and 22nd June, 1914, also could not land (1, 4).

Our knowledge of the geology of Sule Stack is therefore practically nil, and as far as the writer is aware is confined to a single account by Harvie-Brown written as the result of observations from his yacht on one of the occasions when he could not land. Apparently the late Dr. Forster Heddle was also with him (2). This account is as follows :—

" The height of the Stack is 130 feet. A smooth square precipice of a greenish-grey rock, seamed near the top with a broad horizontal dark red vein of felspar, faces the south, and the same, continuing round a very sharply defined angle to the west, also faces the Atlantic. . . . On the north-west side they (the gannets) are equally numerous upon certain broad shelves, where the rock has broken away apparently, in large horizontal masses—great steps of a giant stair! . . . The colour of the whole is very fine. . . the south and west faces of mural precipice—as already mentioned—of an almost glaucous green or grey, and almost lustrous surface, with the intersecting bands of dark red felspar just below the snowy summit."

As no account of the geology of either Sule Stack or Sule Skerry appears in the Geological Survey memoir on *The Geology of the Orkneys*, it is assumed that these islands or rocks were overlooked. It is therefore strange that they appear appropriately coloured as Lewisian Gneiss on the quarter inch Geological Survey of Scotland sheet No. 5. Our knowledge of the geology of Sule Skerry is due to Dr. Walker (7), who has shown that that island is essentially composed of an andesine-anorthosite gneiss.

The study of the geology of Sule Stack presented some unusual difficulties. While it is true that the rock is completely devoid of vegetation, it is covered by the white excrement of the gannets, and in small clefts in the rock this is often several inches deep. This gives the rock a white appearance and successfully masks any structural features. It will at once be obvious that working under these conditions and among some 3,500 gannets is not only difficult but extremely unpleasant. In addition the rock is extremely hard—the writer broke a chisel—and owing to the way in which the rock has weathered into smooth round surfaces, it was very difficult to obtain suitable unweathered specimens for examination.

The topography of the island has already been dealt with. The sheer cliffs of the west and the smooth sloping cliffs of the east seem accounted for by the predominance of the westerly swell. In the winter a heavy sea coming from the west would strike against the westerly cliffs and a large amount of water would be thrown over the top to run down on the eastern side. The only other features resultant on the weathering are the narrow gully between the two portions of Sule Stack with the accompanying cliff structure like giant stairs, and a further narrow gully or cave in the western cliffs which connects with a large vertical shaft reaching the summit of the rock near the extreme northern end. Owing to the impossibility of approach the cause of these lines of weakness could not be investigated. As at Sule Skerry, the rock appears generally to dip towards the south-west at a high angle.

From five specimens obtained from the northern part of Sule Stack it would appear that the rock is composed of a moderately coarse-grained orthogneiss of specific gravity 2·78. Unlike the neighbouring Sule Skerry, the rock of Sule Stack is not constant in composition and in the hand specimen varies in colour from light grey to black according to the amount of ferromagnesians present. In places the rock is traversed by small pink pegmatite veins and shatter belts.

Under the microscope it would appear that the essential mineral constituents of the rocks vary only in percentage and not in kind.

The rock is chiefly composed of plagioclase and orthoclase felspars which rarely constitute less than 50 per cent of the rock, and in some cases attain a percentage of 70 to 75. The felspar is chiefly a plagioclase and most sections exhibit it in an altered or "moth eaten" condition. Lamellar twinning is fairly common, but owing to the weathered state it is difficult to find suitable sections to determine the extinction angle. It has, however, a mean refractive index greater than oil of cloves (rather an unknown quantity), greater than ethylene dibromide but less than ortho-nitrotoluene. The refractive index is therefore between 1·536 and 1·546, making the felspar an oligoclase. This oligoclase has not the same contorted appearance that is so apparent in the andesine of Sule Skerry.

The chief other mineral is green hornblende which is strongly pleochroic and has an extinction angle of 18 degrees. Some sections show distinct alteration towards chlorite which is often fringed with magnetite. Rounded grains of colourless augite are present in most sections, but they show little tendency to alteration towards hornblende. In all cases the amphibole is more abundant than the pyroxene. Small crystals of apatite are present in all sections, and secondary quartz in a few.

Half-way down the eastern side of the northern portion of Sule Stack a piece of black basic rock was obtained that showed hornblende in excess of the felspar.

None of the specimens obtained of the gneiss of Sule Stack were as fresh or clear as specimens from Sule Skerry and this of course makes comparison difficult. There are certain general resemblances between the two rocks, but at Sule Stack the rock is less calcic, making the plagioclase felspar oligoclase compared with andesine, and has a greater percentage of ferromagnesians—including augite—than the rock of Sule Skerry. An analysis of the most unweathered specimen from Sule Stack was made by Miss H. Bennett and is given here together with the analysis by N. Sahlbom of Dr. Walker's specimen of rock from Sule Skerry. The nearest approach to the analysis of the rock from Sule Stack given in Washington's tables is that of a diorite. These two analyses compare favourably, and indeed from a purely mineralogical standpoint the rock of Sule Stack could be considered as a diorite.

The "norms" of these three analyses have been worked out, and again comparing the rock of Sule Stack with that of Sule Skerry the less calcic nature, the smaller proportion of felspar and the greater percentage of ferromagnesians of the former are at once apparent, as has already been proved by examination of the rock. In view of this it does not seem justified to call the rock of Sule Stack an anorthosite-gneiss, though in some respects it approaches it, and for lack of a better name the writer prefers to call it a hornblende-gneiss.

There is little to say concerning the pegmatite veins. They are all small in size, often measuring only a few inches in breadth, and are composed of typical pink microcline felspar and white or grey quartz. A moderate sized dyke, or vein, is to be found on the summit of Sule Stack, while small veins are apparent on the southern portion of the rock near the gully dividing the island.

ANALYSES.

	A.	1.	2.
SiO_2	55·12	53·74	55·28
Al_2O_3	20·35	24·39	17·23
Fe_2O_3	1·90	0·63	1·54
FeO	3·93	2·52	6·23
MgO	2·55	2·67	2·69
CaO	5·65	9·47	5·60
Na_2O	5·47	4·77	5·42
K_2O	2·03	0·66	2·12
H_2O +	0·96	0·94	0·71
H_2O –	0·17	0·14	0·20
CO_2	nil	—	0·04
TiO_2	1·00	0·08	1·64
ZrO_2	—	—	trace
P_2O_5	0·63	0·37	0·73
Cl	—	—	0·07
F	0·10	—	0·28
FeS_2	—	—	0·07
Cr_2O_3	trace	—	—
V_2O_3	0·01	—	—
MnO	0·07	0·03	0·24
BaO	0·04	—	0·06
SrO	—	—	trace
Li_2O	—	—	trace
	99·98	100·41	100·15
O = F, Cl	0·04	—	0·13
	99·94	100·41	100·02
Sp. Gr.	2·78	—	2·822

A. Gneiss from northern portion of Sule Stack. Analyst, H. Bennett.

1. Gneiss from west end of Sule Skerry. Analyst, N. Sahlbom (7).

2. Diorite quoted from Washington's Tables (page 448). Analyst, W. F. Hillebrand.

"NORMS."

	A.	1.	2.
orthoclase	11·68	3·89	12·79
albite	46·11	40·35	45·59
anorthite	24·46	43·09	16·68
corundum	0·31	—	—
diopside	—	1·36	5·29
hypersthene	9·26	5·38	10·41
olivine	0·76	3·32	0·69
magnetite	2·78	0·93	2·32
ilmenite	1·98	0·15	3·19
apatite	1·34	1·01	1·68

SUMMARY.

Sule Stack is composed of an orthogneiss traversed by shatter belts and small pegmatite veins composed of microcline and quartz. The chief constituent minerals of the gneiss are oligoclase and orthoclase felspars, hornblende altering towards chlorite, augite, and apatite. In addition some sections show magnetite and a few quartz. Comparisons are made between the gneiss of Sule Stack and that of the neighbouring island of Sule Skerry.

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(4) —— "The Gannetry of 'The Stack', Orkney Islands," *The Ibis*, 1914, pp. 631–4.
(5) STEWART, MALCOLM. "Notes on the Gannetries of Sule Stack and Sula Sgeir," *British Birds*, xxxi, 1938, 282–94.
(6) —— "Notes on the Geology of Sula Sgeir and the Flannan Islands," GEOL. MAG., LXX, 1933, 110–16.
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REVIEWS.

GEOLOGICAL EXCURSION GUIDE TO THE ASSYNT DISTRICT OF SUTHERLAND. By M. MACGREGOR and J. PHEMISTER. pp. 62, with 4 coloured maps and 3 text-figures. Edinburgh Geological Society, 1937. Price 2*s*.

WE congratulate the Edinburgh Geological Society heartily on the publication of this Guide, which is in no sense a rival of the well-known guide to the Assynt Model of the Geological Survey, but a supplement to it. Its object is to help geological visitors to find the most interesting sections, with exact direction as to paths, together with warnings against falling down precipices in mists. There is no need to attempt to criticize the contents, which are authoritative, since the authors are members of the Geological Survey. We will only say that the age of the Moines is wisely left uncertain. The small coloured maps, three inches to the mile, are delightful; they are the size of the page, not folded, a great advantage in the field in such a climate.

A Sedimentary Petrological Investigation of a Number of Sand Samples from the South Coast of Greenland. By R. D. Crommelin. *Meddelelser om Grönland.* Band 113, No. 1, pp. 32.

The material here investigated comes from a well-known area of highly alkaline rocks, being partly local products of denudation of such rocks and partly travelled moraine material. As might be expected, the characteristic minerals of nepheline-syenites were found to be abundant, and a feature strange to British sedimentary petrographers is the rarity of zircon, rutile, garnet, tourmaline, and the metamorphic silicates of alumina. Also muscovite is very scarce. In some of the sands consisting of local material the heavy fraction $> 2{\cdot}9$ is said to amount to 70 per cent or even more.

CORRESPONDENCE.

HEERLEN CARBONIFEROUS CONGRESS.

Sir,—I have received the February number of the Geological Magazine, in which on p. 90 there is a review of the first volume of the Compte Rendu of the Heerlen Carboniferous Congress. Referring to the last sentence of this review on p. 91, I would like to point out that it is possible to order the volumes bound in cloth, at an extra cost of Fl. 3 for each.

W. J. Jongmans.

Heerlen.
5th February, 1938.

A PLEISTOCENE STRAND LINE IN THE VALE OF YORK.

Sir,—In reply to the questions which Mr. Edwards addressed to me (Geological Magazine for January, 1938):—

(i) If the Higher Terrace is of " late Hessle age ", what is the age of the later Lower Terrace ?

Obviously " later late Hessle "; possibly Postglacial. For this reason I ignored it in my first letter. There does not appear to me to be any justification whatever for exalting it into the position of a grand index in Glacial Chronology. On page 72 of my book I drew attention to the resemblance between the height and fauna of the Overton deposit and those of Miss M. E. Tomlinson's Second River Terrace of the Warwickshire Avon, but did not mention the

10 ft. terrace, for the reason already given. On the opposite bank of the River Ouse there is a terrace whose back is 15 feet and its front edge 10 feet above the alluvial flat. This place is north of the York moraine. The same terrace may be seen between Bishopthorpe and Naburn. These places are between the York and Escrick moraines.

(ii) Where does the Leeds *Hippopotamus* fit into this scheme ?

It fits comfortably into the place I have already indicated in my book (p. 88).

(iii) Why do I correlate the Leeds *Hippopotamus* deposit with those at Woodlesford ?

Because I know of no evidence which forbids it. Fossils have not so far been found at Woodlesford ; in other respects the two deposits are the same. Writing of Woodlesford, Prof. A. Gilligan remarks :—" The deposits are undoubtedly of deltaic origin, laid down in a lake or pool, and are not such as are ordinarily formed by rivers in such a part of their course." (*Proc. Yorks. Geol. Soc.*, xix, 1918, 255.)

On page 115 of his paper Mr. Edwards writes : " The balance of evidence points to the 100 ft. submergence having preceded the York-Escrick glaciation." The Higher and Lower Terraces are demonstrably later than the York-Escrick glaciation. The 100 ft. Strand Line and the Terraces are not contemporaneous. They can not therefore be correlated, even at the cost of misusing the term " fiord " (or " fjord ").

SIDNEY MELMORE.

YORK.
12th January, 1938.

CHONETES SPECIOSUS nom. nov.

SIR,—In Volume LIX, 1922, of the GEOLOGICAL MAGAZINE, Professor L. B. Smyth described a new species of *Chonetes* which is abundant in the shales associated with the main limestone near Ballycastle, Ireland. This species he named *Chonetes elegans*. As the trivial name is preoccupied by *C. elegans* L. G. de Koninck 1847, and Professor Smyth has left the choice of a new name to me, I suggest :—

Chonetes speciosus = *C. elegans* L. B. Smyth 1922 *non C. elegans* L. G. de Koninck 1847.

F. WOLVERSON COPE.

GEOLOGICAL SURVEY OFFICE,
270 OXFORD ROAD,
MANCHESTER.

THE FLOOR OF THE ARABIAN SEA.

Sir,—The " John Murray " Expedition to the Indian Ocean has been so prolific of important scientific results that it may seem somewhat ungracious to call into question any of the deductions drawn from actual observation. Nevertheless, the geological interpretations given in the article by Dr. J. D. H. Wiseman and Col. R. B. Seymour Sewell in the Geological Magazine of May, 1937, contain a number of statements which I feel are misleading and cannot be allowed to pass without comment.

(1) *Khorya Morya Islands.*—The statement is made on page 223 that the granite is intrusive into an overlying sandstone formation of Miocene age. I have not visited these islands personally, but I have examined the adjacent coastline at Dhofar and there the basement gneiss is overlain by a " Nubian " type of desert sandstone which in turn is overlain by Cenomanian limestones (*Quart. Journ. Geol. Soc.*, lxxxiv, p. 588). By inference from other parts of Arabia, these crystalline rocks are of pre-Cambrian age and there can be no question on the Khorya Morya Islands of their intruding an overlying formation, which according to Carter is of Eocene age.

(2) " *Scarp faulting* " *along the Arabian Coast.*—The soundings along the Arabian coast have given most interesting results which are described in more detail in Vol. 1, No. 2, of the main report (p. 49). " The slopes are extremely irregular, consisting of alternate slopes and valleys running out to seaward, in appearance similar to that of a mountain side. While steaming along a course parallel to the shore in the vicinity of the 100 fathom line, the soundings were never constant, varying perhaps from 60 to 360 fathoms in very short distances. The similarity to a mountain side was illustrated by the large quantities of scree dredged off the slopes of the Khorya Morya Islands." This submarine topography is interpreted as indicating (p. 223) " in all probability extensive scarp faulting ". To my mind it is in reality what it appeared to be, namely submerged mountain sides. I have shown (*Quart. Journ. Geol. Soc.*, lxxxiv, p. 611) that there are excellent examples of drowned valleys on the Musandam peninsula, indicating negative movements of the land of at least 1,000 feet, and these recent observations seem to show that similar conditions continue along the south-eastern Arabian coast as well.

(3) *Rift Valleys in the Arabian Sea.*—It has been difficult enough hitherto to understand the structural connection between Oman and the Kirthar Ranges, and I feel that any new proposal which will not stand up to critical examination should be challenged. The discovery of a double ridge is surely an insufficient basis for the postulation of a Rift Valley. The Murray Ridge lies on the prolongation of a system of fold-ranges and there is, therefore, no justifiable analogy with the African Rift Valleys which break through ancient

rigid masses. The same objection may not be so valid in the case of the Carlsberg Ridge, but even there I should regard it as a very improbable explanation. The earthquake evidence can be equally well interpreted as indicating a fold system.

(4) *The Age of the Carlsberg Ridge System* (p. 229).—I have already questioned the evidence for faulting along the south-eastern Arabian coast, and the limestones of the Khorya Morya Islands are of Eocene and not of Miocene age. In Oman well-defined terraces with sub-recent shelly deposits have been elevated to as much as 1,130 feet above sea-level, and I agree that the present configuration of the ridges found by the expedition are probably of comparatively recent age. Undoubtedly, however, they follow the trend of older fold systems which, according to evidence in Oman, may be of any age from Upper Cretaceous onwards.

Finally, I should like to make my principal criticism of the observations of the expedition, namely that, like Oliver Twist, I ask for more. The area surveyed is intensely interesting from so many aspects and I sincerely hope that it will be possible to continue the work on a later occasion. In particular, some pendulum observations along and across these submarine ridges would be most important. The single traverse across the Carlsberg Ridge by Meinesz indicates the magnitude of the gravity differences which can be expected, and by this means only could the difficult problem of the ultimate destination of the Oman and the Kirthar Ranges approach solution.

G. M. LEES.

THE WHITE HOUSE,
CHIPPING ONGAR.
ESSEX.

ANNOUNCEMENT.

THE Council of the Institution of Petroleum Technologists, with the co-operation of an Organizing Committee in Scotland, is arranging a Conference to be held in Scotland from 6th June (Whit-Monday) to 11th June, 1938, under the Presidency of Sir T. H. Holland, K.C.S.I., F.R.S.

The objects of the Conference are mainly to provide the opportunity for a review of the present state of knowledge regarding the geology, mining, treatment, and utilization of shale and cannel in all countries where these materials occur; and to consider the problems of increasing oil supplies from indigenous sources of such materials. The programme will include visits of inspection of the operations of the Scottish shale industry.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXV.

No. IV.—APRIL, 1938.

ORIGINAL ARTICLES.

On the Differentiation of the Glen More Ring-dyke, Mull.

By Cath. Koomans, University of Leyden, and
Ph. H. Kuenen, University of Groningen.

Introduction.

THE Glen More Ring-dyke furnishes one of the finest examples known of an intrusive body showing a gradual transition from a basic to an acid part. It has been fully described in the Mull Memoir (1) [1] and Bailey and Thomas have there given a masterly exposition of the problems involved. After carefully weighing the evidence they draw the conclusion that gravitational differentiation in situ must be held responsible for the variation in rock types.

In explanation of certain features, that will be mentioned in the sequel, they believe that after most of the gabbroic minerals had crystallized out of the original basic magma, there was a pause in the crystallization over a range of temperature, during which a residue of interstitial granitic liquid filtered upwards owing to lighter specific gravity and formed the granophyre.

Of latter years doubt has been cast on this explanation by Holmes. He advocates the view that the partial mixing of two magmas gives a better explanation of the facts; see, for instance (3, p. 49), (7, p. 235). Fenner (10) also raised objections to the explanation of the Memoir.

In 1936 the second author had an opportunity of collecting samples from the type locality of Cruach Choireadail. Preliminary examination showed that this material would supplement and extend the range of data if chemical analyses were made. In view of the great theoretical importance of this case to petrology in general it appeared worth while to add four new analyses to the six already made for the Mull Memoir. The first author undertook this part of the investigation in Professor Escher's laboratory at Leyden.

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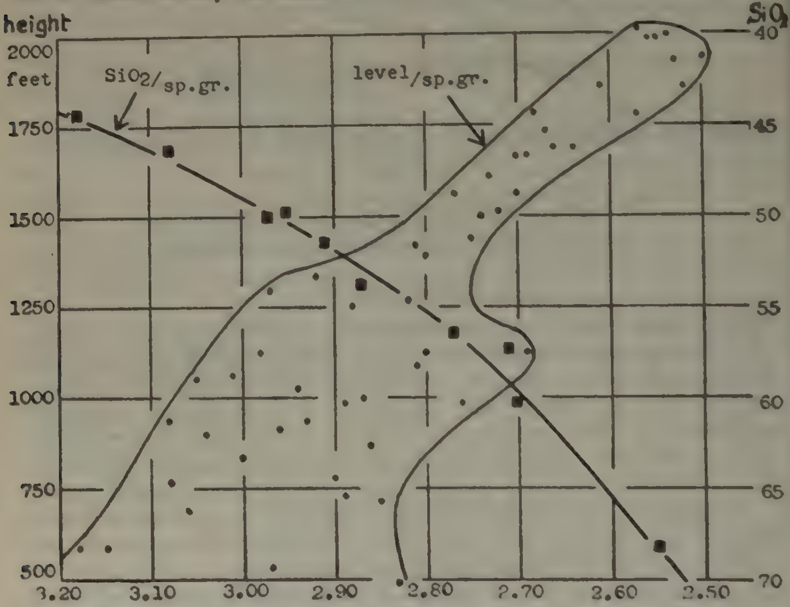
[1] Figures in parentheses refer to bibliography at end of paper.

DATA.

For a full account of the features of the Glen More Ring-dyke the reader is referred to the Mull Memoir. Here only a brief summary together with the new data can be given.

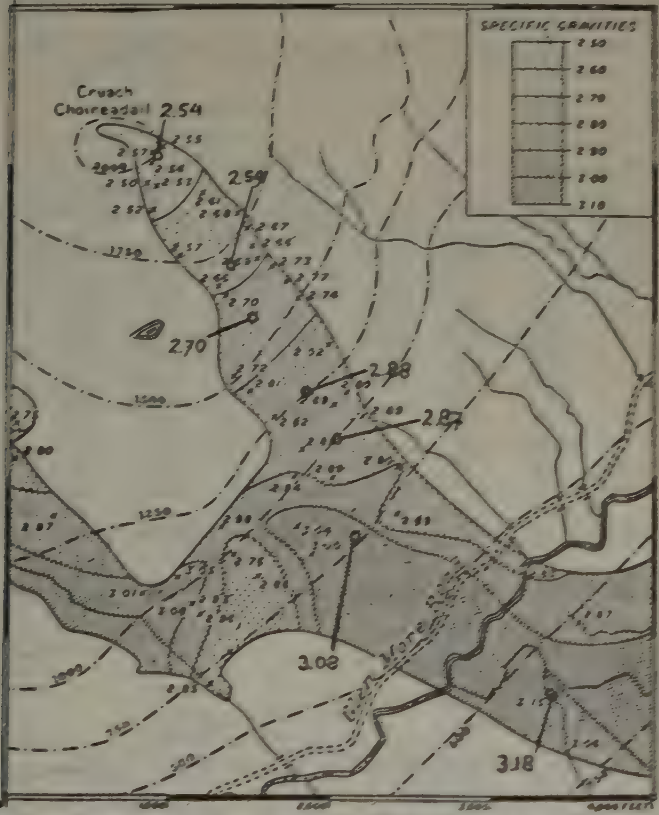
This ring intrusion is one of the larger of its kind and is well exposed over a considerable vertical range at several localities. At all of these it may be observed that the upper parts are occupied by a pale granophyre that grades downhill into darker, more basic rocks of augite-diorite affinities and finally to a gabbro or dolerite. The transition is quite gradual, no eruptive breccias or sharp margins between the various rock types can be found. The only exceptions are several horizontal acid veins up to 1 m. broad intersecting the more basic lower portion of the mass, with sharp but unchilled margins.



TEXT-FIG. 1.—Altitude and SiO_2-percentage plotted against specific gravity, Cruach Choireadail.

A number of samples was collected by Clough along the steep face of Cruach Choireadail, where a vertical range of 500 m. is exposed. The specific gravity was determined and a map and graph drawn to show the remarkable regularity of the transition. We can add a few new determinations, and Text-fig. 1 shows the specific gravity plotted against altitude. Text-fig. 2 demonstrates that the divergencies from the average have a systematic distribution in the field, so that the regularity of the phenomenon is even greater than Text-fig. 1 suggests. (The investigated samples are added to the map of the Memoir.)

To the six analyses given in the Memoir we are now able to add four new ones, two of which carry the differentiation series down from 50 per cent to nearly 44 per cent SiO_2, the other two filling in the largest gaps in the older series.



TEXT-FIG. 2.—Map of Cruach Choireadail, showing distribution of specific gravity.

In the Memoir the microscopic character of the rocks is treated in detail. The chief points of interest are as follows. The gabbro is composed of sub-ophitic augite, labradorite, and iron-ore. The plagioclase shows zoning, corrosion, and replacement by less basic plagioclase. This alteration is clearly attributable to the action of acid material of later consolidation. Chlorite replaces earlier olivine.

In our slides 150 and 149 there is no corrosion of the plagioclase, although there are some rare patches of graphic quartz and felspar in between the other minerals. The slight traces of crush mentioned in the Memoir are also absent. A small amount of pyrite also occurs. No sure indications of former olivine are found in our slides and part of the chlorite is seen to derive from augite. As the chlorite is less than 10 per cent, former olivine can in no case have been more than about 5 per cent.

Our slide 148 resembles the description in the Memoir. As it is less basic than 150 and 149 the latter two must represent a step further in the basic direction than had been covered by the Memoir.

TABLE I *a*. ANALYSES OF GLEN MORE RING-DYKE.

	150	149	I	V	II	148	III	VI	146	IV
SiO_2 .	44·30	46·35	49·90	50·04	51·32	53·53	56·22	57·18	60·23	68·1
TiO_2 .	2·39	2·20	2·56	2·56	0·98	2·04	2·74	3·25	1·54	1·2
P_2O_5 .	0·23	0·21	0·20	0·28	0·24	0·22	0·50	0·46	0·22	0·2
Al_2O_3 .	11·94	14·62	12·70	13·32	13·96	14·62	12·45	10·75	14·66	13·0
Fe_2O_3 .	9·63	6·33	4·20	4·71	2·48	4·52	3·09	4·96	4·18	1·0
FeO .	9·75	8·33	7·88	8·07	7·10	6·68	7·58	6·24	3·98	3·2
MnO .	0·38	0·37	0·36	0·33	0·34	0·31	0·43	0·32	0·26	0·3
MgO .	6·74	5·97	5·88	5·01	5·78	3·60	2·78	2·15	2·00	0·7
CaO .	11·01	11·24	10·39	10·02	11·51	6·61	5·93	5·73	4·40	1·8
BaO .	—	—	—	—	—	—	0·04	0·06	—	0·0
Na_2O .	1·81	2·66	2·86	3·28	3·50	2·88	3·82	4·62	4·08	4·1
K_2O .	0·52	0·56	0·95	1·08	1·16	1·93	2·67	2·67	2·50	4·4
$+ H_2O$	1·38	1·09	1·65	1·45	1·27	2·14	1·35	1·31	1·02	1·1
$- H_2O$	0·12	0·10	0·67	0·27	0·36	0·32	0·44	0·33	0·41	0·4
CO_2 .	—	—	0·09	0·08	0·09	0·30	0·05	0·08	0·46	0·0
sum .	100·20	100·03	100·29	100·50	100·09	99·70	100·09	100·11	99·94	100·1
spec. grav.	3·18	3·08	2·95	2·97	2·91	2·87	2·77	2·71	2·70	2·5

I–IV and 150–146 Cruach Choireadail.
V, VI Coir' an t-Sailein.
I–VI Anal. E. G. Radley (Memoir, p. 29).
150–146 Anal. C. Koomans.

Higher up in the sequence we may note a distinct increase of late-consolidated acid residuum. The augite is columnar. The corrosion of the labradorite is a marked characteristic, but olivine has disappeared. Still higher the rock is more finely grained and the felspars are less basic. The acid mesostasis is collected into better defined patches and strings. Towards the summit the rock has become a granophyre in which the early formed felspar and augite are reduced to a minimum and have suffered marked alteration.

Table II shows that the increase in SiO_2 goes hand in hand with an increase of the amounts of plagioclase, graphic, and free quartz and a decrease in ore, but especially in augite (all chlorite was measured as augite). The greater basicity of 150 as compared to 149 is not due to a higher percentage of ore only (as a superficial comparison of the analyses might suggest). There is also a considerable alteration in the ratio of plagioclase and augite in favour of the latter. This is of importance as it clearly demonstrates that 150 is not a patch with local accumulation of ore, but that all factors working towards basicity elsewhere were acting normally in this

TABLE I *b*. NIGGLI-VALUES FOR CRUACH CHOIREADAIL.

	150	149	I	II	148	III	146	IV
al . .	15	19·5	18·5	20	25	23·5	30	36
fm . .	55	47	46	40	42	42·5	34	22·5
c . .	25·5	27	27·5	30	21	20·5	16·5	9·5
alk . .	4·5	6·5	8	10	12	13·5	19·5	32
si . .	95	104	122	124	156	181	210	318
ti . .	3·86	3·64	4·71	1·74	4·55	6·56	2·51	4·48
p . .	0·26	0·27	0·29	0·29	0·35	0·77	0·42	0·56
h . .	10·69	8·90	19·2	11·76	24·00	19·11	16·51	24·37
k . .	0·17	0·12	0·18	0·18	0·31	0·40	0·29	0·42
mg . .	0·39	0·42	0·47	0·51	0·37	0·32	0·31	0·22
c/fm .	0·46	0·57	0·59	0·74	0·49	0·49	0·49	0·41

TABLE II. MODAL COMPOSITION OF ROCKS AND PLAGIOCLASE.

	150	149	147	148	146	145	144
Plagioclase .	44	51		58	30		
Augite .	44	39		24	(14) 16*		
Iron Ore .	12	10		7·5	(4) 2*		
Micropegmatite	trace	—		7·5	52†		
Quartz . .	—	—		3			
% An . .	50–55	± 60			15–20	5–10	0–10
centre	55–60	± 55	50–55	45–50	± 20	5–8	0–5
rim .	50–55	30–40	20–25	20–25			
centre	55–60			40–45	± 20	5–10	
rim . .	40–45			±20			
spec. gr. . .	318	3·08	2·88	2·87	2·70	2·59	2·54
% SiO_2 determined or found from fig. 1 .	44	46	52½	54	60	65	70

* Secondary iron-ore replaces part of the augite; the figures between brackets were actually measured.

† Groundmass containing also plagioclase; the figure for plagioclase is therefore too low.

TABLE III. NORM-COMPOSITION OF ROCKS FROM CRUACH CHOIREADAIL.[1]

	150	149	I	II	148	III	146	IV
orthoclase . .	3·7	3·4	5·6	7·1	12·6	17·0	14·8	27·6
albite . . .	17·2	24·9	26·5	32·3	28·3	25·5	45·4	38·3
anorthite . .	24·5	28·3	21·1	19·7	22·2	15·7	8·4	4·1
per cent An in plagioclase .	59	53	49	38	44	38	16	10
dark const. . .	43·9	33·5	41·0	36·6	34·2	33·3	22·4	11·5
magnetite . .	11·2	7·7	4·9	3·3	—	—	—	—
quartz . . .	− 0·5	2·2	0·9	1·0	2·7	8·5	9·0	18·5

case too. The more acid slides were not amenable to planimetric treatment.

The development of the plagioclase is no less arresting than the other tendencies. In the basic series (150–147) the first formed plagioclase is of fairly uniform composition with slightly more than 50 per cent anorthite. The acid rims, however, become broader and more albitic. In the three last slides the An-percentage decreases from about 20 to 10 and 5. The measurements were carried out on larger crystals that were sufficiently intact from acidification (see also p. 158). The results are graphically represented in Text-fig. 4, together with the calculated composition.

DIFFERENTIATION OR HYBRIDIZATION ?

If the Glen More Ring-dyke consisted of normal rocks throughout there would be little reason for doubting the explanation of the differentiation by gravity during crystallization. But a complication is introduced by microscopic examination. It is found that the middle part is characterized by rocks of which the plagioclase has been acted upon at a late stage of consolidation by the more acid mesostasis. According to the Memoir, part of this action is due to " . . . the general albitization to which most rocks within the central region of Mull have been subjected, . . .". But it is " often clearly distinguishable from the albitizing effect produced by the acid residual magma " (p. 325). The explanation offered in the Memoir, and the controversy between Nockolds and Holmes centre around this point.

The authors of the Memoir held that an undifferentiated mass was injected and that the action of gravity during the consolidation caused the differentiation. " After crystallization had proceeded for some time, and had practically exhausted the magma as regards lime and magnesia, there still remained a residuum which retained its fluidity over a considerable range of temperature, so that there was, at this stage, a marked pause in the process of crystallization.

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[1] For method of calculation see Niggli and Lombaard (5).

Under such conditions, ample opportunity was afforded for migration of the fluid residuum under stress during the extended period that elapsed before crystallization was completed." (Memoir, p. 330.)

Nockolds (who is not specially concerned with the Glen More Ring-dyke) also holds that the primary, tholeiitic magma differentiated by crystallization, but in a deeper reservoir (6 and 8). Two strongly contrasted magmas were formed and intruded separately. The acid magma then reacted with the basic crystals in the middle part where the two were in contact during the final crystallization.

Stress is laid upon the fact that a special kind of basic rock is always associated with the same acid residual liquid, thus proving consanguinity: in other words that they were generated by differentiation and not brought together from separate sources.

Holmes criticized the above theories. His chief points are that the idea is inconsistent with the physico-chemical principles of crystallization-differentiation because intermediate products must also be formed. Further, the amount of acid residuum cannot be more than about one-tenth of the total and could therefore only be squeezed out by powerful deformation. In his opinion two contrasted magmas were available and were intruded separately, the acid one after the basic one. They may have been generated separately or by transfusion (action of emanations and heat on pre-existing acid rocks).

The two points of view cannot be adequately treated in this short summary; the reader is invited to study the originals. But it is hoped that the main points at issue have been made clear.

The present authors wish to emphasize in advance that the material dealt with in this paper is far too restricted to allow of a definite conclusion on the basic problems of magma genesis. The following should therefore be taken as appertaining only to the case of the Glen More Ring-dyke and to be offered tentatively as a contribution to, not as a solution of, the question at the head of this section.

The variation-diagram must first be considered. In discussing the analyses the Memoir says (p. 28): "It is obvious that these analyses fit with wonderful precision the values given . . . for the Normal Series of Mull." A few minor differences are then noted: MgO of the ring-dyke decreases more steeply, Na_2O is higher throughout, K_2O is higher in the middle. These statements now need qualification: the basic end of the series shows a different tendency. Iron is 4 to 5 per cent higher around 45 per cent SiO_2 and the curve is concave upwards. CaO is a couple of per cent higher and shows no tendency to fall away at the basic end. MgO, instead of rising steeply from 5 to 8 per cent over the last 5 per cent SiO_2, remains almost constant at 6 per cent and the line is concave downwards. Na_2O is constant at 2·5 per cent over the same range for the Normal Magma Series, but in the ring-dyke it decreases from 3 to 2 per cent.

It now appears that the basic end of the variation diagram shows much more resemblance to the corresponding part of the Ardnamurchan Tonalite and Quartz-monzonite Magma Series. (Ardnamurchan Mem., pp. 88–91.) In both we note the exceptional rise of iron, and the constant CaO at 11 per cent; Na_2O and K_2O are also similar. The only differences of importance are the continued rise of MgO and TiO_2 and the fall of Al_2O_3 in the Ardnamurchan series.

The magmas of the Tonalite Series are accounted for in the Memoir by the assimilation of basic material in representatives of the Porphyritic Central Magma-type. But hornblende and biotite are characteristic minerals in the rocks of this series and in contradistinction with our rocks, and the variation diagram is entirely different for the whole range above 50 per cent SiO_2. There is so little in common between the two series viewed as a whole, that no argument in favour of hybridization can be deduced for the Glen More Ring-dyke from the similarity of the most basic magmas. On the contrary we are inclined to conclude that hybridization (at least of the type responsible for the Tonalite Series) was *not* active.

Returning to the comparison with the Normal Series it should be noted that the most significant differences between the two diagrams are the concentration of iron in the ring-dyke and magnesia in the Normal Series. In the former section it was noted that olivine appears to play a minor part in the ring-dyke even in the ultra-basic rocks. We will first attempt to explain these matters by crystallization-differentiation, leaving aside other possibilities. Expressed in terms of crystallization-differentiation the two facts noted above appear to indicate that in the normal series the crystallization and sinking of olivine and plagioclase played a part, while in the ring-dyke iron-ore and pyroxene were the dark constituents that were chiefly responsible.

The matter is somewhat more complicated, however. In the Normal Series are represented the successive stages of differentiation of the plateau-basalt as the first formed crystals (olivine, ore and basic plagioclase, and later augite and intermediate plagioclase) are abstracted. At each stage in this process injection has taken place and the magma is then quickly cooled and preserved unaltered. In general each rock of this series belongs to the more acid magma available at its time of chilling. The rocks enriched by addition of sunken crystals belong to other magma series (Porphyritic Central Type with plagioclase grading into anorthosite; eucrite grading into allivalite with olivine, basic plagioclase and iron-ore; see Ardnamurchan Memoir, pp. 91 and 96–98).

In the Glen More Ring-dyke olivine is not of importance, showing that a less basic magma was intruded than plateau-basalt. Yet the resemblance to the Normal Series in the intermediate and acid part indicates that the injection belonged to this series. Evidently a magma of about 50 per cent SiO_2 of the Normal Series first filled the Glen More Ring-dyke.

The supposed primary magma has almost exactly the average composition of the Whin Sill (2, p. 539), but the alkalis are slightly higher and CaO lower.

Gravitative crystallization-differentiation then evolved the more acid parts. The intermediate parts have a slightly different history to those of the Normal Series. In the latter case abstraction was the chief process; in our case addition from higher levels also took place. The result is almost identical because over this range the variation diagram is almost straight lined. As the added material is more acid than the abstracted for a given part of the magma, it moves a short distance to the right in the diagram, but does not diverge from the lines.

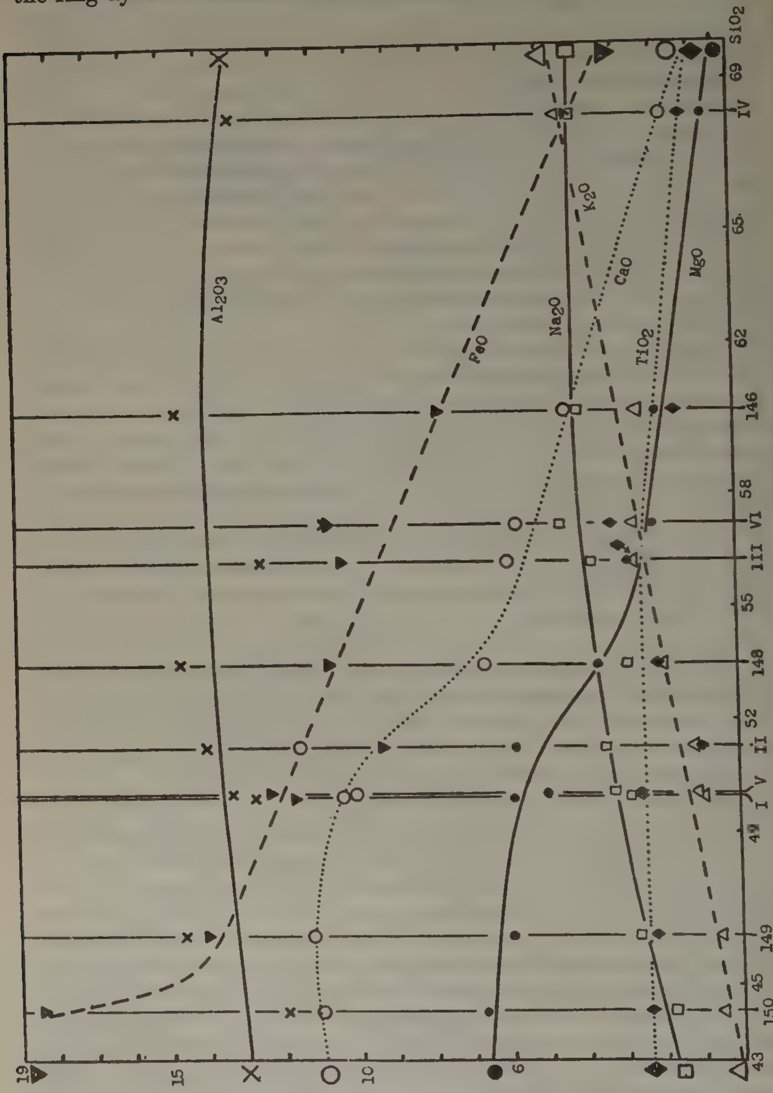
Towards the basic end, however, a marked difference with respect to all the other series must be found. The anorthosite is formed by concentration of plagioclase, the allivalite by plagioclase, augite and especially olivine. In our case pyroxene and iron-ore were concentrated without olivine and little plagioclase. In the Normal Series the primary magma without any concentration forms the basic end of the series.

It would appear that the composition of the *magma* series of the ring-dyke can be explained by gravitative crystallization-differentiation without other assumptions than are postulated for this theory in general.

The most extreme point of view in hybridization would be the assumption of two separate magmas, the acid having been injected after the basic. The variation must then be explained by mixing. (Holmes, 1936, pp. 234–5, 1929, p. 49.) But the mixing of two *magmas* can only produce straight-line variation diagrams. In this mixing there is no element that can cause an oxide to collect into a part of the magma leaving the other oxides more or less behind. And this is what is needed to cause warping of the variation lines. Inspection of the variation diagram shows that only K_2O and possibly Al_2O_3 form straight lines.

It is obvious that besides pure mixing another process would have to be called upon to explain the variation series. This process must be able to remove from or add to the intermediate magma part of practically all of its components. The addition or subtraction of one oxide (MgO, SiO_2, or any other) would cause all other lines to bend together in the opposite sense. But as they each show their individual, typical warping, each element must have undergone an influence of its own throughout the entire range in a manner as individual and typical.

Contamination of one of the two magmas before the mixing would not cause curved lines. Assimilation after the mixing might have the right effect. As no metamorphism from the neighbourhood of the ring-dyke is mentioned in the Memoir, and as it cuts through a



TEXT-FIG. 3.—Variation diagram of Glen More Ring-dyke.

variety of rocks, this contamination theory does not appear to lead to a satisfactory solution.

Another influence that could have altered the mixture would be emanations from deeper regions. The various mixtures must be supposed to have selected different proportions of the various elements from the rising volatiles. This process is rather complicated and necessitates the assumption of volatiles containing appreciable amounts of practically all the principal oxides of the magma. There is not much appeal in this point of view.

A different possibility would be the intrusion of one of the magmas, after the consolidation of the other. In a highly interesting paper (9) Miss Reynolds has shown how transfusion of quartzite results in rocks forming a variation diagram with curved lines, in consequence of differential migration of the major magmatic constituents into the quartzite. The case described by her, however, is very different both in respect to dimensions and chemistry. Moreover in the Glen More Ring-dyke there are no sharp margins or inclusions and the interaction must be supposed to be restricted to the rocks within the ring-dyke.

Finally, crystallization-differentiation after the mixing could be held responsible for the curvature of the variation lines. As the basic pole of the variation diagram is an almost pure mixture of the minerals causing the differentiation, their abstraction or addition must move a magma along the straight-lined connection between its original composition and that of the basic pole (or a composition not very far from it). Moreover the magmas between 55 and 70 per cent SiO_2 form a straight-lined variation diagram and they must therefore all have lost proportionate amounts of cafemic oxides to account for the concentration in the basic series. The amount of deviation from straight lines shown by our variation diagram can evidently only be a fraction of the total amount of differentiation the members of the series must actually have undergone. But if the hypothesis of mixing must also take into account a not inconsiderable amount of gravitative crystallization-differentiation, it has lost much of its appeal and the objections still to be mentioned add their evidence against it.

There are other objections to the explanation through hybridization. If there had been two more or less uniform parts with a transitional zone in between, the idea of mixing or contamination would be rational. But actually we find a gradual change from the lowest exposures up to the very summit of the mountain, that must lie practically at the original top of the ring-dyke. Neither the specific gravity nor the chemistry show a transitional " zone ", for that term would imply adjoining parts of uniform composition. There is a gradual and remarkably regular transition throughout the entire exposure. This being the case the only logical explanation by hybridization would be to postulate original magmas of more extreme compositions than the most acid and basic terms of the exposure. The most acid rock exposed has a specific gravity of 2·50 and the graph, Text-fig. 1, shows that it must contain about 71 per cent SiO_2. The acid magma would have to be less basic, therefore of pure granitic composition. But the basic magma would have to contain less than 44 per cent SiO_2. This in itself is improbable. Besides, the only ultra-basic magma known from these regions is allivalitic, in which MgO is three times as high and iron three times as low and the other constituents also show marked differences. To render the conception of hybridization reasonable one must therefore assume the injection of an ultra-basic magma of quite exceptional composition. With gravitative crystallization-differentiation the exceptional composition is readily explained by the nature of the sinking crystals (augite and iron-ore instead of olivine) and the basic magma need not have been mobile as it was developed in situ.

Finally, the hybridization hypothesis would have to meet the obstacle, that there are no feeding dykes. The most acid members lie topmost although injected last (this is the normal sequence in composite intrusions). These members must have risen through the basic part almost without contamination (otherwise the SiO_2 percentage could not be so high). The only manner in which this could take place would be along fissures. But vertical fissures are absent and the basic magma must have been fluid to allow of mixing. If the fissures were microscopic and traversed a consolidated rock the acid material that finally won through to the summit would have been in such intimate contact with the hot basic matter that it could no longer be of granitic composition. Moreover experience has taught that an acid intrusion in a composite dyke takes on a different aspect, forming a single dyke along the centre of its basic forerunner or developing a breccia. A magma that is not excessively charged with volatiles is too viscous to ooze through microscopic interstitial apertures.

Holmes suggests the possibility that the acid magma rose through the basic as a kind of emulsion and therefore shows no feeders. The difference in specific gravity between the two magmas is of the same order of magnitude as between a magma and the basic minerals crystallizing from it. If it is supposed that the emulsion split into its two components, why should crystallization then not be followed by important gravitative differentiation? Is it not improbable, finally, that two successive injections from different sources took place in about the same proportions all along the course of a ring-dyke, and even into both branches where it forks, as on Cruach Choireadail?

The various mechanical obstacles to the idea of mixing seem no less important than the chemical.

We now come to the point raised by Holmes, that the amount of acid differentiate can only have been small and could not be ejected from between the meshwork of crystals. This question is bound up with a remark in the Memoir, to the effect that this acid portion migrated upwards. In our opinion the process of differentiation must be imagined in a slightly different manner. When a basic mineral forms and sinks, it travels for a long distance downwards, but there is no complementary displacement upwards of acid material, there is only a slight upward movement of the whole column of liquid through which it sinks. While the basic magma is formed by the addition of material from a large part of the reservoir, the acid magma is generated by abstraction and no new material is added to it. It has undergone cleansing by precipitation. We do not need to suppose that first 90 per cent of the magma crystallized to a meshwork from which the mesostasis was ejected. But the concentration of the acid material is gradual, starting from the time the first crystals begin to sink. As these crystals are removed the acid portion remains entirely fluid until the increasing viscosity and decreasing overweight of the crystals bring the sinking to an end. By the time a rhyolitic composition has been attained the bulk need only be a few per cent of the whole reservoir, but it may still be quite free from crystals. Probably the exposed part of the ring-dyke is but a minor portion of the whole bulk of intruded magma. A rough estimate of the average specific gravity of the ring-dyke between the summit and deepest exposure on Cruach Choireadail is 2·81, corresponding to an SiO_2 percentage of 55. The supposed primary magma of the ring-dyke is actually more basic.

In the foregoing pages an attempt has been made to demonstrate that the composition of the *magmas* may be successfully explained on the principles of gravitative crystallization differentiation, but that hybridization meets with difficulties at every turn. It now remains to explain the *mode* of the *rocks*, especially the curious phenomena exhibited by the rocks of intermediate composition.

It should be emphasized that although the intermediate magmas of the Normal Series and of the ring-dyke were almost identical in composition, the microscopic picture of the rocks that crystallized from them is different. The noteworthy acidification of the basic plagioclase that took place at a late stage in the consolidation is more marked in our rocks than is generally the case (Memoir, pp. 18–20). As the difference is therefore restricted to the mode of the rocks, it appears more reasonable to seek for an explanation in the conditions of consolidations than in the generation of the magma. But even in this mode the abnormality is found to be less striking than microscopic investigation alone would lead one to believe. The close agreement between the micrometric and calculated mineralogical composition of the rocks militates against the view that the mode is very exceptional.

The data on An-percentage of Table II were found by Fedorov measurement of larger, unaltered plagioclases.[1] The clear and regular zoning proves that they cannot have been much acidified because in other individuals this process is seen to result in irregular corroding. These data are brought together in a graph, Text-fig. 4, and the remarkable fact is brought out that the decrease in the An-percentage is even more gradual than that found by calculation from the chemical composition. Even before the acidification the An-percentage of the plagioclase formed a series through the entire column of the ring-dyke as regular as the series of the other properties. Most decidedly there was a complete and gradual chain of variation from top to bottom before in final stages of consolidation the " hybridization " phenomena were evolved.

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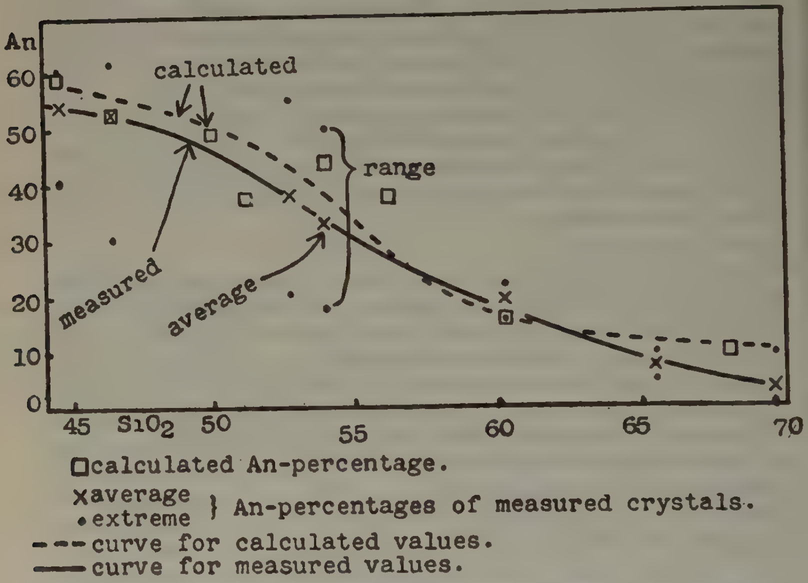
[1] It is sometimes difficult to interpret the measurements of acid plagioclases, but we believe we have arrived at the given compositions with sufficient accuracy.



TEXT-FIG. 4.—An-percentage of plagioclase plotted against SiO_2-percentage of the rocks.

The Memoir says (p. 28): " . . . the migration of the acid residuum, impelled by gravity, has led to differentiation . . .". We believe we have shown that the gravitative differentiation had already taken place before (if ever) the acid residuum started to migrate.

The only respect in which the analyses show any appreciable difference between the rock of the ring-dyke and of the Normal Series, is the higher percentage of Na_2O and K_2O in the former. It is doubtful whether this small difference is sufficient to cause the acidification of the plagioclase. One would expect normal rocks to crystallize with plagioclase slightly richer in albite.

Now there is much resemblance between the general albitization to which most rocks within the central region of Mull have been subjected and the albitization of the Glen More Ring-dyke. The former alteration took place in completely crystallized rocks and is also traceable in the ring-dyke. Could it not be that towards the end of the crystallization of the ring-dyke a pneumatolitic effect was produced by emanations coming from the basic part of the dyke? The basic pole may have arrived at the final stage of consolidation (when the enclosed volatiles are concentrated in a few per cent of mobile liquid) before the more acid upper regions. The pneumatolysis around the vent proves the ability of such emanations to traverse consolidated rocks through microscopic channels. Is there any inherent obstacle to supposing that similar emanations rose into the partly consolidated upper portions, mobilizing the mesostasis and causing reaction between it and the solid plagioclase? The chilled contacts of the upper regions of the ring-dyke indicate movement upwards of the still liquid acid cap. A movement of this type could be purely mechanical and consequent on ring-dyke or cone-sheet intrusion in the neighbourhood.

To the present authors it appears that the explanation here offered has the advantage over the view expressed in the Memoir that it fits in more smoothly with the results of experimental petrology, and explains the gradual transition through the whole column of all components, both felspars and dark constituents. The influence of gravity is supposed to be paramount during the liquid stage and not after the crystals already formed a mesh-work.

SUMMARY.

New analyses are given of the Glen More Ring-dyke. The basic end of the variation diagram is found to differ considerably from that of the Normal Magma Series. The magma variation is explained by gravitative sinking of augite and iron-ore (and plagioclase), the olivine of the Normal Series playing only a subordinate part. Various objections are brought forward to the explanation of the magmas by hybridization. The peculiar *microscopic* aspect of the intermediate rocks is tentatively attributed to pneumatolytic emanations from the lower reaches of the column. It is shown that a gradual transition from basic to acid already existed before the final consolidation of the magma took place.

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Progressive Regional Metamorphism in Southern New Zealand.

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Introduction.

DURING the past ten years a number of papers dealing with progressive regional metamorphism in the southern portion of New Zealand have been published. In the following pages a brief summary of the assemblages of minerals typical of the various metamorphic zones is given, but the writer's main object is to draw attention to certain mineralogical and structural peculiarities that appear to differ in some degree from what are usually regarded as the normal features of regional metamorphism in such classic areas as the Scottish Highlands and the Caledonian chain of Norway. The possibility that such departures from the normal may in some instances be connected with chemical peculiarities in the parent rock is suggested by such phenomena as the well-known general limitation of chloritoid, staurolite, and low-grade garnets to pelitic rocks of special chemical compositions. Other unusual features, especially when found to recur in widely separated regions, may well be governed by some particular combination of physical rather than chemical conditions.

From the standpoint of distribution, the metamorphic rocks of southern New Zealand may conveniently be divided into three groups:—

(1) A belt of low-grade schists (Central Otago Schists, Maniototo Series, or Wanaka Series) extends north-west from near Dunedin on the east coast to the Main Divide west of the heads of Lakes

Wakatipu and Wanaka. On the south-west these rocks pass with decreasing metamorphism into phyllites, slates, and sheared greywackes of the Te Anau and Clinton Series (Marshall, 1918; Turner, 1935), while on the north-east they are flanked by non-fossiliferous greywackes and slates of the North Otago mountain-ranges. Triassic fossils occur in sheared greywackes in the vicinity of Mt. St. Mary, North Otago, but there is no definite transition between these rocks and the Central Otago schists (Mackie, 1936, p. 142).

(2) North-west of the main divide the grade of metamorphism increases and the low-grade Central Otago schists pass gradually into the gneisses, schists, and hornfelses of South Westland, which are here considered as a separate unit on account of the high grade of metamorphism attained in that district.

(3) The south-western corner of the island from the Hollyford River southward is occupied by the Fiordland injection-complex, which includes a variety of schists and gneisses invaded by granites, diorites, and norites. The relation of these rocks to the low-grade schists lying to the east has not been established, since the eastern boundary of the Fiordland complex is defined partly by the boundary of a Tertiary and Pleistocene cover, and partly by what appears to be a zone of great dislocation more or less parallel to the line of the Hollyford and Eglinton Valleys.

No agreement has yet been reached as to the age of the metamorphic rocks nor to the date at which metamorphism was brought about. Rocks ranging in age from Lower Ordovician to perhaps late Palaeozoic have been affected by metamorphism in one or more of the three regions defined above. If the writer is correct in his interpretation that all the schists and gneisses of New Zealand assumed their metamorphic condition in a single orogeny, then an upper limit to the date of metamorphism is supplied by pebbles of schist, hornfels, and gneiss in conglomerates of mid-Triassic to Jurassic age in both islands (Bartrum, 1935; Mackie, 1936; Turner, 1937). The available evidence thus indicates that the metamorphic rocks of southern New Zealand range from Lower Ordovician to perhaps Permian in age, and that the metamorphism was accomplished in late Permian or early Triassic times. The semi-schistose condition locally developed in the Triassic rocks (cf. Mackie, 1936), and the effects of retrogressive metamorphism sometimes shown by the high-grade rocks of South Westland are attributed to subsequent movements, especially those connected with the Hokonui Orogeny of the late Jurassic.

THE CENTRAL OTAGO SCHISTS.

For details of petrography and distribution of the Central Otago schists, the reader is referred to papers by Professor W. N. Benson (1928) and the writer (Turner, 1933, pp. 182–7, 1934, 1935, 1936; Hutton and Turner, 1936). The rocks are mainly quartzo-feldspathic schists derived from greywackes that consisted originally of quartz, plagioclase, and less plentiful augite or hornblende. True pelites are relatively rare, but green-schists corresponding to basic tuffaceous rocks are rather widely distributed. In schists[1] originating from greywacke the assemblages most commonly developed are quartz-albite[2] epidote-chlorite and quartz-albite-epidote-actinolite, but sericite is often a minor constituent, especially in the first of these. The usual associations in the green-schists are albite-epidote-chlorite-calcite, albite-epidote-chlorite, and albite-epidote-actinolite-chlorite, though in some rocks albite may fail and in others quartz may enter in small amount. Rocks rich in sericite (sericite-chlorite-quartz and sericite-chlorite-quartz-albite-epidote) represent a more or less pelitic composition. Several highly ferruginous rocks have been recorded, the best known being magnetite-epidote-chlorite-schists and haematite-sericite-albite-schists, the latter containing minor quartz, epidote and chlorite. Manganese-bearing rocks include relatively rare quartz-muscovite-piedmontite-garnet-schists (Turner, 1933 *a*) and various rocks in which manganiferous garnet is prominent. Sphene, magnetite, apatite, tourmaline, and zircon are widely distributed in most of the rocks enumerated above. Minerals of the stilpnomelane group are widespread and sometimes are sufficiently plentiful to rank as essential members of mineral-assemblages, e.g. in the stilpnomelane-garnet-calcite-schist described by Turner and Hutton (1935).

Complete absence of red-brown biotite in the Central Otago Schists is one of their most characteristic features, and even the green biotites commonly found in low-grade schists of appropriate composition in other parts of the world are here very rare. The rocks of the Central Otago group therefore fall within a Chlorite Zone based upon mineral-assemblages in derivatives of greywacke. The intensity and hence temperature of metamorphism seem to have varied a good deal within this Chlorite Zone, for the ultimate products include sheared greywackes, fine-grained non-foliated[3] schists, coarse well-foliated schists, and rocks in which the structure is almost gneissic. In all of these, however, the same assemblages of reconstituted minerals occur, so that it is impossible to subdivide the Chlorite Zone by isograds based upon index-minerals. In collaboration with Mr. C. O. Hutton the writer has established four subzones based upon the stage to which reconstitution has proceeded in rocks derived from greywacke[4] (Turner, 1935, pp. 344, 345;

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[1] Mr. C. O. Hutton has recently found pumpellyite as an abundant constituent in some schists of this type (*Min. Mag.*, 1937, vol. 24, No. 157, pp. 529–533).

[2] The content of anorthite in the albite of schists in the Central Otago region is never greater than 5 per cent.

[3] The terms *foliated* and *non-foliated* are used throughout in the sense employed by Harker, 1932, p. 203.

[4] Compare the metamorphic zones established by Knopf and Jonas (1929, p. 123) in Pennsylvania.

Hutton and Turner, 1935). In order of increasing intensity of metamorphism these have been defined as follows :—

Subzone Chl. 1.—Greywackes retain their original clastic structure ; schistosity has not developed ; slight cataclasis is evident and an interstitial matrix of reconstituted minerals (epidote, chlorite, calcite, actinolite, sphene) has commenced to form ; feldspars are converted to saussurite or are much sericitized.

Subzone Chl. 2.—Greywackes give place to semischists in which clastic structure has been partially obliterated, the grain-size reduced by shearing, and a definite schistosity has developed ; chemical reconstitution is far advanced but not yet complete.

Subzone Chl. 3.—Schistosity is well developed and is accentuated by incipient, rather ill-defined foliation ; the original clastic structure has disappeared, but a few relict grains still persist ; chemical reconstitution is practically complete ; average grain-size of quartz and albite ranges from 0·02 mm. to 0.2 mm.

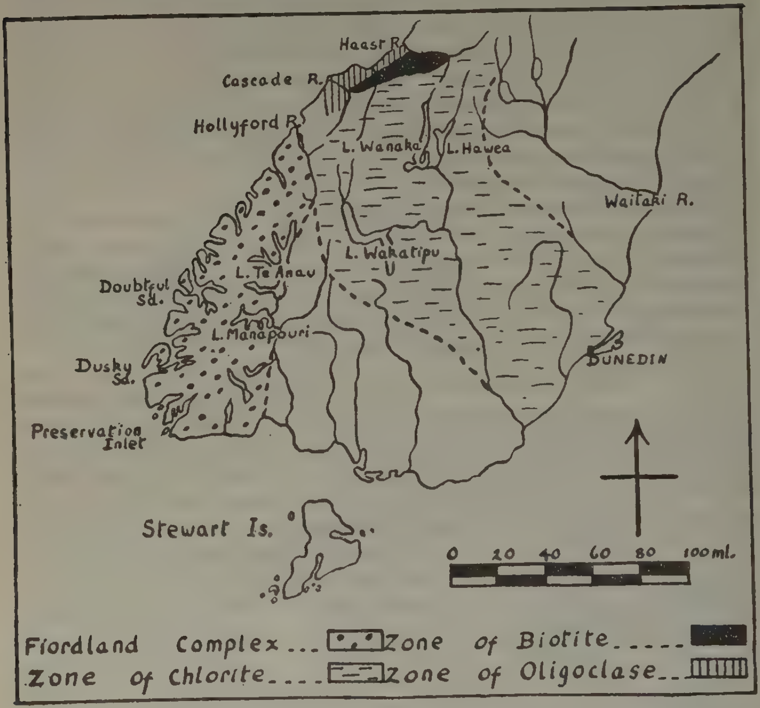
Subzone Chl. 4.—The characteristic rocks are coarse schists in which the average size of the grains of quartz and albite ranges from 0·25 mm. to 2 mm. ; schistosity and foliation are highly developed, quartz-albite foliae sometimes being 8 mm. to 10 mm. in thickness.

Attention is drawn to the following unusual features persistently shown by the schists of Central Otago :—

(*a*) In both quartzo-feldspathic schists and green-schists actinolitic amphibole may crystallize at the lowest as well as at higher grades within the Chlorite Zone. In an account of the metamorphic rocks west of Lake Wakatipu (Turner, 1935, pp. 345–7) evidence has been presented indicating that amphiboles of this type are here members of true equilibrium-assemblages, and the hypothesis is advanced that the alternative development of chlorite alone, with calcite, or with abundant actinolite in the rocks of Subzones Chl. 1 to Chl. 3, depends upon the amount of available water and carbon dioxide, and the degree to which bases such as lime may be progressively removed from the reacting system by circulating solutions. This conclusion is opposed to the recently expressed views of Dr. Wiseman and Professor Tilley, that actinolite can persist at the lowest grades only as a metastable component (Wiseman, 1934, pp. 374, 411, 416).

(*b*) The widespread occurrence of stilpnomelane commented upon above is an unusual feature for which no satisfactory explanation can yet be offered. It occurs in rocks of all grades within the Chlorite Zone, but has not yet been observed beyond the biotite isograd.

(*c*) It has been suggested (Turner, 1933, p. 244) that the Chlorite Zone as determined for quartzo-feldspathic schists in Central Otago and South Westland probably includes some rocks of rather higher grade than those of the Chlorite Zone as defined for pelites in Scotland. This may prove to be a general condition for all schists derived from greywackes, since comparison of data recorded by Bailey (1923) with the map accompanying Tilley's classic paper of 1925 shows that in the albite-gneisses of the south-west Highlands the association chlorite-muscovite remains stable within part of the Biotite Zone of pelites. Harker (1932, pp. 243, 244) explains the co-existence of chlorite and muscovite in arenaceous rocks of the Scottish Biotite Zone as the result of failure of mutual reaction on account of the sparse distribution of the individual crystals concerned, but adds that where the two minerals have recrystallized in close proximity " we are probably to recognize the influence of superior rigidity of arenaceous rocks, in virtue of which they sustain a more intense shearing stress ". This second explanation probably applies to the rocks of Central Otago, for in many of the coarsest schists of Subzone Chl. 4 chlorite and muscovite are concentrated together in the " micaceous " as opposed to the quartz-albite foliae, and flakes of the two minerals frequently are interleaved.



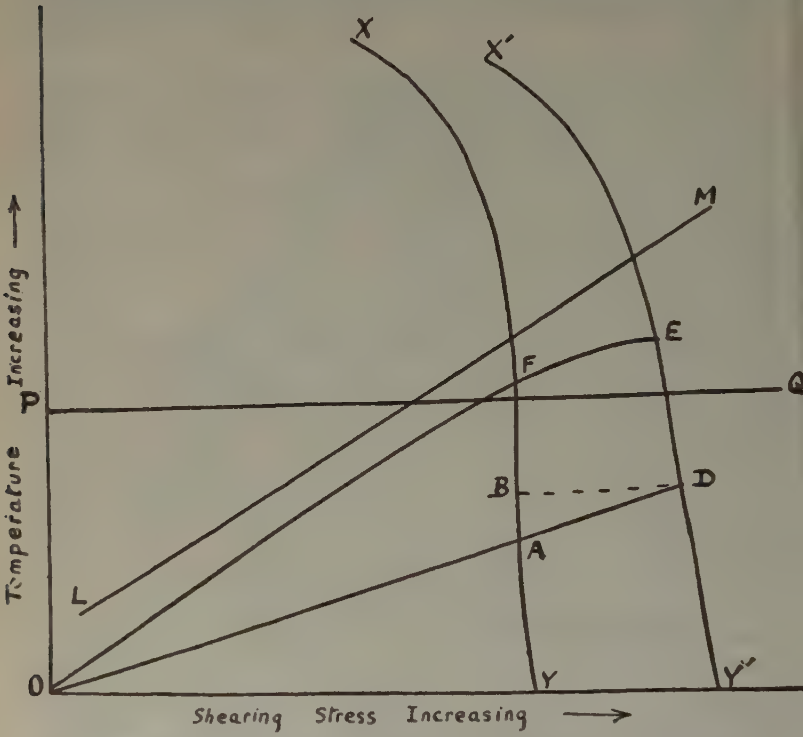
TEXT-FIG. 1.—Sketch-map of the southern portion of the South Island of New Zealand, showing approximate location of principal known areas of regionally metamorphosed rocks. (Local outcrops of covering strata and intrusive igneous rocks are not indicated.)

(*d*) The schists of the most widely developed subzone in Otago (Chl. 4) appear to be unusually coarse, compared with typical Chlorite Zone schists from other parts of the world.

(*e*) The great extent of the Chlorite Zone in Otago is remarkable. It occupies an area approximately 100 miles long (parallel to the main strike) by about 70 miles wide. The high-grade zones of biotite and oligoclase in South Westland are not nearly so extensive (see Fig. 1).

It is generally agreed that high shearing-stress and relatively low temperatures are the principal conditions that govern crystallization of low-grade mineral-assemblages such as are characteristic of the schists of Otago. In the present case this is fully borne out by details of microstructure (Turner, 1936, pp. 211-14). The structural evolution of the typical coarse-grained schists involves three main processes: mechanical granulation and shearing out of the original clastic grains, simultaneous growth of minute crystals of new minerals with their long axes in subparallel position, and subsequent increase in size of the reconstituted mineral grains. Mimetic crystallization (*Abbildungskristallisation*) following temporary cessation or diminution in tectonic activity is sometimes the essential feature of this third process (cf. Sander, 1930, p. 172), but there is widespread evidence to show that shearing continued actively even to the last stages of crystallization in many rocks. In many sections, too, indications of tectonite orientation are obvious for certain minerals, and this has been confirmed by partial analysis of the quartz fabrics of several rocks (Turner, 1936, pp. 215–223). Further the schistosity of Otago schists frequently shows the pronounced linear element so characteristic of the B-tectonite.

It has been argued convincingly by Harker (1932, pp. 182–4) that in normal regional metamorphism the shearing stress is constantly maintained at the maximum value possible for a given type of rock at a particular temperature—a value that decreases steadily as the temperature rises. He further points out (loc. cit., p. 187) that " the maximum possible shearing stress at a given temperature may be much greater in one type of rock than another ", a fact of great significance in view of the manner in which the fields of stability of many minerals vary with shearing stress. In Fig. 2 (a modification of Harker's Fig. 80) the curves XY and X′Y′ represent the maximum possible shearing stress sustained respectively by pelitic rocks and derivatives of greywacke, with rising temperature and pressure. The curves are of course hypothetical since quantitative data are not available. The line LM is the hypothetical boundary between the fields of stability of biotite above, and chlorite-muscovite below; its general direction is determined by the fact that the range of temperature through which biotite is stable will be decreased with increasing shearing stress. It is obvious from the figure that the Chlorite Zone for greywackes and their metamorphic equivalents will include rocks corresponding to part of the Biotite Zone as defined for pelites (cf. Harker, 1932, p. 187). Now high-grade schists are generally much coarser in grain than rocks of lower grade (e.g. see Barrow, 1912, p. 276), i.e. rapidity of reconstitution is dependent upon the temperature maintained during metamorphism. In Fig. 2 an arbitrary line PQ may therefore be drawn at a hypothetical



TEXT-FIG. 2.—Diagram showing hypothetical conditions controlling low-grade regional metamorphism in Otago. XY and X′Y′ represent maximum possible shearing stress sustained in pelitic rocks and greywackes respectively; LM = boundary between the fields of stability of chlorite-muscovite (below) and biotite (above); PQ = minimum temperature requisite for rapid chemical adjustment.

limiting temperature below which growth of individualized grains of new minerals can take place only slowly. The changing physical conditions experienced during metamorphism of greywacke within the Chlorite Zone may be represented by a line such as ODEFO, but the final structure and composition of the resultant schist would be determined by that part of this line lying above PQ. For such a rock the opportunity for development of coarse structure is clearly greater than for a typical pelitic chlorite-muscovite-schist. This possibly explains the unusually coarse grain of quartzo-feldspathic schists in Subzone Chl. 4 of the Otago Chlorite Zone.

Turning once more to Fig. 2 it will be seen that the courses OAB and OD represent corresponding early stages in metamorphism of interstratified pelite and greywacke respectively. Before the maximum possible shearing stress D is attained by greywackes, the pelitic rocks have commenced to yield along the interval AB, and schistosity (slaty cleavage) is thus already well developed in pelitic members, while associated greywackes are still in the non-schistose or poorly fissile condition characteristic of the Chl. 1 Subzone.

The Biotite and Oligoclase Zones of South Westland.

In the extreme south of Westland west of Lake Wanaka the schists of the Otago Chlorite Zone give place to rocks of higher grade, an account of which was published by the writer a few years ago (Turner, 1933). In the Haast Valley section, where the conditions of genesis appear to have been rather simpler than farther south, schists of greywacke composition fall into three zones based upon the index-minerals chlorite, biotite, and oligoclase respectively. This district has been greatly disturbed by later movements and the present outcrops of the various zones are often bounded or at least modified by major faults.

The Biotite Zone is marked by the incoming of biotite, at first yellowish-brown but soon assuming the typical red-brown tint characteristic of high-grade biotites. By far the commonest rocks are coarse-grained, well-foliated schists derived from greywackes and consisting of quartz, basic albite, red-brown biotite, muscovite, and clinozoisitic epidote, with brown tourmaline and apatite as accessories. Typical green-schists consist of basic albite, yellowish-brown biotite, calcite, epidote, chlorite, and minor quartz and actinolite ; where the latter is abundant it has a deep blue-green tint for the Z vibration-direction. Rarer assemblages recorded from this zone are albite-epidote-quartz (with minor biotite and chlorite) and magnetite-haematite-garnet-quartz-actinolite.[1]

The rocks of the Oligoclase Zone are coarse in texture and at high grades of metamorphism may assume a gneissic structure. The anorthite-content of the plagioclase is greater than 10 per cent, provided sufficient epidote to supply the necessary lime is present, and varieties as calcic as $Ab_{65}An_{35}$ have been observed. In the green-schists a dark blue-green amphibole (probably a somewhat aluminous member of Kunitz's actinolite-glaucophane series) is always abundant. A number of typical assemblages are as follows :—Quartz-oligoclase-biotite-muscovite (with or without epidote) ; andesine-quartz-biotite-muscovite ; amphibole-oligoclase-epidote-biotite-magnetite-quartz (sometimes with minor chlorite). Sphene is present in the green-schists, and tourmaline and apatite are widely distributed in rocks of all types. The writer's view that the Oligoclase Zone as defined for rocks derived from greywackes is approximately equivalent to the zones of almandine and perhaps even kyanite as developed in pelitic schists was based upon comparison with the results obtained by Phillips (1930, pp. 247–250) in Scotland and Vogt (1927) in Norway. The recent work of Wiseman (1934) on Scottish epidiorites, and especially the investigations of Ambrose (1936) upon the greywackes of the Missi Series of Canada lend further support to this conclusion. Absence of garnet in the South Westland rocks of the Oligoclase Zone is a striking feature, due primarily to the chemical composition of the rocks in question. In schists derived from greywackes the chlorite is used up completely in the production of biotite before the oligoclase isograd is reached, and a large excess of muscovite is present in rocks of higher grade, while in green-schists the excess of chlorite surviving beyond the Biotite Zone apparently reacts with epidote to give amphibole. In neither group, therefore, is chlorite available to give garnet at grades corresponding to the Almandine Zone of pelites. It is interesting to note that in the rocks described by Ambrose, though similar conditions appear to hold, small quantities of garnet do form by some means at present obscure (Ambrose, 1936, p. 269).

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[1] Qualitative chemical tests indicate a manganiferous variety.

In Westland the effects of purely regional metamorphism caused by folding were modified to some extent by approximately simultaneous uprise of a granitic batholith with subsequent injection of innumerable veins of pegmatite into the immediately adjacent rocks. In the Haast Valley section the principal effect of this invasion was to contribute towards maintaining high temperatures in the Oligoclase Zone, thus facilitating recrystallization and reconstitution; at the same time small amounts of potash-feldspar and probably some muscovite were introduced from magmatic sources and tourmaline was widely disseminated. Further south in the Cascade Valley conditions were rather different. Here the intrusion rose into higher levels outside the zone of maximum regional metamorphism, and a great series of hornfelses and allied rocks has developed, the structure of which has been determined largely by contact influences. The typical assemblage is quartz-oligoclase-biotite-muscovite, though the relative proportions of the component minerals vary greatly. Andalusite is rarely present and tourmaline, ubiquitous as an accessory, may occasionally rank as an essential constituent. Near large dykes of pegmatite the hornfelses have locally been altered to coarse sillimanite-bearing gneisses, while introduction of potash-feldspar, muscovite, and coarse apatite is also fairly common in the vicinity of pegmatite contacts. All these rocks have been mapped as falling within the Oligoclase Zone, for it is difficult to distinguish sharply between areas in which the metamorphism is essentially regional and those where contact influences have dominated.

THE SCHISTS AND GNEISSES OF FIORDLAND.

In Fiordland extensive plutonic intrusions, predominantly granitic and dioritic, but also including more basic rocks such as norites, have invaded sedimentary rocks, most of which have suffered intense regional metamorphism. The least-altered members of this series, as exposed in the vicinity of Preservation Inlet, are slates and greywackes containing abundant graptolites of Lower Ordovician age. These show gradual transition into high-grade schists and gneisses. Intrusion and regional metamorphism occurred during a single period of tectonic activity, but their relative order was, perhaps, not constant through the whole region. Further complication arises from possible combination at any one locality of regional, contact, and injection metamorphism of variable intensity. As a result of repeated and prolonged erosion, the surface now includes large areas of plutonic rocks interspersed with masses of high-grade metamorphics and injection-gneisses. The invaded rocks attain their maximum development along the western border of the complex, especially between Doubtful Sound and Preservation Inlet.

Much of the district is geologically unexplored, but records and descriptions of rocks from a number of isolated localities give some indication of the main features of the complex as a whole, while the recent work of Professors W. N. Benson and J. A. Bartrum (Benson, 1933; Benson and Bartrum, 1935) has for the first time given coherent petrological details with reference to a large continuous area. In a paper still in the press (Turner, 1937) the writer has subsequently given details of the gneisses and plutonic rocks around Lake Manapouri.

In the vicinity of Preservation and Chalky Inlets the intrusions may have been emplaced immediately before the main regional metamorphism (Benson and Bartrum, 1935, p. 133), though there is evidence to show that rather high shearing-stress prevailed near the deep-seated contacts at the time of intrusion (*loc. cit.*, p. 122).[1] The metamorphic grade is lowest in the south-west and increases steadily in a north-easterly direction regardless of proximity to the invading granites. Though it is impossible to draw definite isograds, there is a broad three-fold division of the district as follows:—

(*a*) A south-western zone of low-grade regional metamorphism combined with contact alteration of variable intensity. The principal rocks are slates, greywackes, and quartzites in which the only dynamic effects are development of slaty cleavage in pelitic members and incipient granulation of quartz in more arenaceous types. Growth of spots composed of the same minerals as constitute the enclosing matrix is universal in these rocks, and crystallization of scattered flakes of biotite is not uncommon, both of these characters being due to the contact influence of the invading granites. Along the south-western margin of the main intrusion there is also a narrow belt of true hornfelses consisting of cordierite, quartz, biotite, and sericite.

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[1] The present writer considers that the facts recorded are not incompatible with the hypothesis that intrusion closely followed upon regional metamorphism.

(*b*) A middle zone of contact-schists and injection-schists combining the structural and mineralogical characters of hornfelses and medium-grade schists. Typical assemblages are quartz-plagioclase[1]-biotite, biotite-sericite-quartz, andalusite-cordierite-biotite-sericite-quartz, quartz-labradorite-hornblende-biotite, quartz-plagioclase-biotite-tourmaline.

(*c*) A north-eastern zone where the grade of metamorphism is uniformly high and is independent of the distance from granite boundaries. Assemblages of minerals similar to those listed under (*b*) above are widely developed but garnet enters into the composition of a number of rocks, and assemblages such as quartz-biotite-sillimanite and quartz-biotite-sericite-sillimanite occur. There are also calc-silicate rocks containing diopside, wollastonite, vesuvianite (probably diaphthoretic), microcline and biotite, analogous to the calc-silicate hornfelses recorded by Williams (1934) from large roof-pendants surrounded by granite on Stewart Island.

It is clear from the incomplete data available that a high grade of regional metamorphism was attained still farther north in the neighbourhood of Dusky Sound. Some typical assemblages recorded here by Professor R. Speight (1910) include plagioclase-hornblende-epidote-quartz, plagioclase-quartz-garnet-pyroxene-hornblende, quartz-biotite-muscovite, and quartz-plagioclase-microcline-biotite-muscovite-sillimanite.

Around Lake Manapouri and near the head of Doubtful Sound the regionally metamorphosed gneisses include associations such as: plagioclase[2]-biotite-quartz, plagioclase-hornblende, plagioclase-hornblende-epidote-biotite, and plagioclase-quartz-biotite-garnet-hornblende. These are considered by the writer to be derivatives of a sedimentary series (mainly greywackes) with interstratified tuffaceous bands or basic lavas; the occurrence of extensive phlogopite-marbles in Doubtful Sound strengthens this view.

An outstanding feature of the Fiordland metamorphic region to which attention has been drawn by Benson and Bartrum (1935, p. 133) is the absence of a Chlorite Zone between the almost unaltered greywackes and argillites of the south-western corner and the highly metamorphosed rocks further north and north-east. The cause of this unusual circumstance appears to be that the regionally metamorphosed rocks of lowest as well as high metamorphic grade have come under the thermal influence of the granitic bathyliths, which in the south-west of Fiordland have penetrated relatively near to the surface. Assuming that regional metamorphism immediately preceded intrusion, then in the zone of lowest grade slaty cleavage was developed in the pelites at low temperature under the influence of shearing stress insufficient to impart schistosity to the more resistant arenaceous rocks; under such conditions growth of new crystals of chlorite would not yet be possible (cf. Text-fig. 3).

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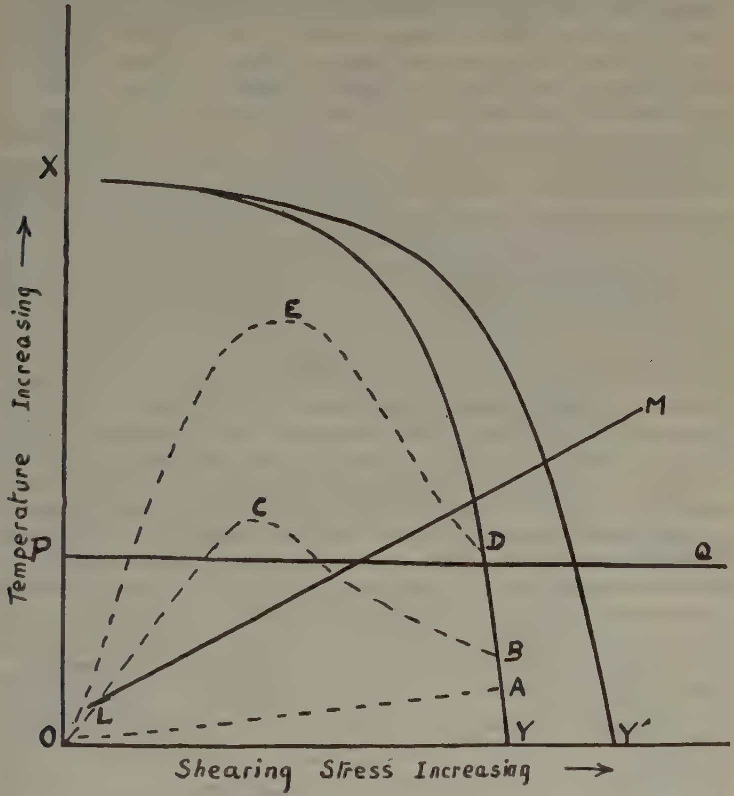
[1] Usually oligoclase.

[2] In the Manapouri gneisses the plagioclase is usually oligoclase or andesine.



Text-fig. 3.—Diagram showing hypothetical conditions controlling metamorphism in South-West Fiordland. XY and XY′ represent maximum possible shearing stress sustained in pelitic rocks and greywackes respectively; LM = boundary between fields of stability of chlorite-muscovite (below) and biotite (above); PQ = minimum temperature requisite for rapid chemical adjustment.

However, as the temperature subsequently rose under the influence of the rising granitic magma, shearing-stress meanwhile having diminished somewhat, the field of stability of biotite was reached and rapid growth of new crystals simultaneously became possible, for the first time. Biotite was thus the first metamorphic mineral to crystallize freely, and there is no zone of chlorite. Further north-east a Chlorite Zone may well have developed during the regional phase of metamorphism, but if so it was subsequently obliterated at the time of intrusion. Here the ultimate assemblages of minerals crystallized under conditions of moderately high temperature and deficient shearing stress, and are thus comparable with certain associations described by Harker (1932, pp. 230–5) from Aberdeenshire, where the rocks were not subjected to their maximum possible shearing stress during regional metamorphism. In Text-fig. 3 the curves OABCO and OADEO represent possible courses of metamorphism for a biotite-argillite and a contact-schist of the Preservation Inlet type respectively.

In conclusion it may be noted that early crystallization of biotite without intervening development of chlorite has been recorded in regionally metamorphosed rocks in other parts of the world. Dunn (1929, pp. 38, 39) has described the occurrence of biotite-argillites in the Singhbhum district of India, where metamorphism, though essentially of the regional type accompanying folding, has been to some extent assisted by the thermal influence of rising granitic magma. Again, Harker (1932, p. 231) states that compared with the normal zones of progressive metamorphism as developed in Perthshire and in Aberdeenshire where shearing stress was deficient " the biotite-zone is extended at the expense of the chlorite-zone ". In his recent detailed account of progressive metamorphism in Dutchess County, New York, T. F. W. Barth (1936) has recorded not only absence of any zone of chlorite, but also the almost simultaneous appearance at the biotite isograd of biotite, almandine, and kyanite. While Dr. Barth specially emphasizes the important part played by igneous intrusion in this metamorphic field, it is difficult thus to explain satisfactorily the peculiarities of the region, and the apparent analogy with the Preservation Inlet area of New Zealand may later prove to be misleading, when the part played by overthrusting in determining distribution of the metamorphic zones in the states of New York and Connecticut is more definitely known (cf. Knopf, 1935).

Retrogressive Metamorphism.

In the high-grade rocks of South Westland and Fiordland, retrogressive effects such as chloritization of biotite, sericitization of feldspar, cordierite and andalusite, conversion of ilmenite to leucoxene, and crystallization of vesuvianite in the calc-silicate hornfelses are often pronounced, especially in the vicinity of major zones of dislocation where completely reconstituted diaphthoretic schists may occur locally (Turner, 1933, pp. 244–251) ; Benson and Bartrum, 1935, pp. 134, 135). This also accounts for the highly cataclastic structure of some of the Fiordland gneisses. In the low-grade schists of Central Otago mineralogical evidence of retrogressive metamorphism is of course lacking, but such features as development of cataclastic structure in quartz-albite segregation-veins of late origin suggest that there may well have been regional shearing subsequently to the main metamorphism. The results of partial analysis of quartz-fabrics in two Otago schists accord with this view, though they are also capable of other interpretation.

The writer believes that these retrogressive and late structural changes were imparted during the great Hokonui Orogeny of late Jurassic times.

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The Diorites and Associated Rocks of the Glen Tilt Complex, Perthshire.

I. THE GRANITES AND INTERMEDIATE HYBRID ROCKS.

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6. ACID HYBRIDS.

1. INTRODUCTION.

THE Glen Tilt Complex, one of the larger masses of the Newer Granites of the Central Highlands, is included in sheet 64 of the Geological Survey of Scotland.[1] The greater part of this complex is a granite which is bounded on the south-west and south-east by an earlier series of intermediate and basic rocks. The granites described in this contribution are restricted to a small area at the south-eastern margin of the large granitic intrusion generally known as the Beinn Dearc granite. The smaller and independent intrusion of the Sron a'Chro' granite and a number of smaller masses of granite associated with the marginal strip of diorites on the north-western side of Glen Tilt have also been examined. These small isolated areas appear to be contemporaneous with the intrusion of the main Beinn Dearc mass and have been intruded between the earlier diorites and the margin of the intrusion, a feature not uncommon in many of the other Scottish Newer

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[1] *Mem. Geol. Surv. Scot.*, "The Geology of Upper Strathspey, Gaick, and the Forest of Atholl," 1913.

Granites.[1] A small independent mass of muscovite-biotite-granite intruded into quartz-mica-diorite occurs on Conlach Mhor. Although these rocks are completely isolated from both the biotite- and muscovite-biotite-granites of the main Beinn Dearc intrusion their essential similarity with the latter leaves no reasonable doubt of their common origin.

2. BIOTITE-GRANITE.

The granite of the main intrusion is badly exposed on the high undulating peaty moorland of Aonach na Cloiche Moire and fresh specimens are difficult to obtain. The undecomposed rock is pink in colour and composed of predominant microperthite and quartz with subordinate plagioclase and biotite. Although the microperthite occurs in individuals up to 5 mm. in length it does not develop a good idiomorphic form, and is usually turbid with minute dusty inclusions. The microperthite encloses small plagioclase laths, but no quartz, and its crystallization range was probably close to that of the quartz. The plagioclase Ab_{91} ($\alpha' = 1{\cdot}532$), which is sometimes rimmed with a thin zone of albite, is usually clear and unsericitized, and many laths showing little sign of corrosion are enclosed within the microperthite, but small patches of myrmekitic intergrowth within the microperthite may represent original small inclusions of plagioclase. Very small squarish crystals of potash-felspar are sometimes present within the plagioclase. The biotite, $\beta = 1{\cdot}646$ is pleochroic from $\gamma =$ dark brown to $\alpha =$ straw yellow, and is altering to a green chlorite. Apatite and magnetite are the commonest accessories, but small idiomorphic zircons with pyramidal terminations, and a few grains of sphene also occur. Towards the contact with the diorites,[2] and the diorite-granite hybrids there is a slight decrease in the grain size of all constituents and although some of the microperthite crystals are still 4 mm. in length, the quartz is distinctly smaller in size and more granular in form. The inclusion of plagioclase laths in microperthite shows a considerable increase and corrosion effects are also more marked, but there is no noticeable change in the character and amount of the biotite and accessories.

3. SRON A'CHRO' GRANITE.

The Sron a'Chro' granite, although in a few localities weathering quite erratically to a white rock, differs from the biotite granite of Aonach na Cloiche Moire in its conspicuous red colour. It is a medium to coarse-grained rock in which the plagioclase weathers more quickly than the microperthite. The granite offshoots veining the sediments in the Allt Sron an Buine at Clais Daimh, and in the Allt Craoinidh close to the Tilt are finer in grain, yellower in colour, and poorer in biotite; the latter feature is, however, frequently reversed during the contamination of these offshoots by enrichment in derived biotite. The microperthite forms hypidiomorphic crystals approximately 5 mm. by 4 mm., enclosing small corroded laths of plagioclase, and has a composition, calculated from the analysis (No. 1) approximating to $Or_{59}Ab_{41}$. The plagioclase, Ab_{92} ($\alpha' = 1·531$) occurs as large individuals (up to 5 mm. in length) showing little sign of corrosion, and also as small laths enclosed within the microperthite. Where no protective border of myrmekite has been developed these small laths are considerably corroded. The early development of the corrosion shows the usual penetrating stringers of potash felspar but the stage is quickly reached in which the mesh of the microperthite gradually increases in size until the original plagioclase laths consist only of optically continuous, isolated squares within the potash felspar, and in the final stage the plagioclase disappears altogether. The quartz forms irregular grains often showing a slight tendency to glomerogranular texture,[1] and is not enclosed by the microperthite. The biotite, $\beta = 1·648$, occurs in flakes up to 3 mm. in length, showing incipient alteration to chlorite, and is pleochroic from $\gamma =$ dark mottled brown, $\alpha =$ yellow green. The accessories are apatite, zircon, magnetite, and epidote, but sphene is absent.

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[1] Barrow, G. and E. H. C. Craig in "The Geology of Braemar, etc.", *Mem. Geol. Surv. Scot.*, 1912, p. 77.

[2] A map showing the detailed distribution of the various rock types will be published later.

ANALYSIS I.

		Norm.		*Mode.*[2]	
SiO_2	69·12	quartz	21·72	quartz	18·9
Al_2O_3	15·99	orthoclase	22·24	microperthite	41·4
Fe_2O_3	0·94	albite	38·77	plagioclase	31·6
FeO	1·38	anorthite	9·45	biotite	8·1
MgO	1·25	corundum	0·92		
CaO	2·16	hypersthene	4·02		100·0
Na_2O	4·62	ilmenite	0·91		
K_2O	3·81	magnetite	1·39		
$H_2O +$	0·35	apatite	0·49		
$H_2O -$	0·11	water	0·46		
TiO_2	0·46				
P_2O_5	0·23		100·37		
MnO	0·01				
	100·43				

1. Biotite-granite. Allt Craoinidh, 1,500 yards from junction with the Tilt. (Anal. W. A. Deer.)

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[1] Hawkes, L. "On a partially fused quartz-felspar rock and on glomerogranular texture," *Min. Mag.*, 1929, xxii, 163.

[2] The modes of all the analysed rocks are volume percentages from a single section of usual size measured on a Leitz integrating stage.

4. MUSCOVITE-BIOTITE-GRANITE.

Towards the centre of the main granite intrusion the biotite-granite of Aonach na Cloiche Moire is succeeded by a muscovite-bearing granite. No contacts have been found between these two granites but they probably represent two successive intrusions, and the small independent mass of muscovite-biotite-granite to the south-east of Conlach Mhor intrudes quartz-mica-diorite with no intervening biotite-granite. The rock of the main intrusion is a little finer-grained than that of the small Conlach Mhor mass, and is also distinguished from the latter by a development of drusy cavities sometimes filled with larger quartz and felspar crystals, and often showing a concentration of comparatively large flakes of muscovite and biotite. In much of the rock all the constituents except muscovite are allotriomorphic in form, and in the case of the plagioclase this is due to corrosion by microperthite, as idiomorphic plagioclase is sometimes developed where the corrosion is not so strong. The microperthite forms irregular plates and corrodes the plagioclase Ab_{95} ($\alpha' = 1{\cdot}530$) whenever the two are in juxtaposition. Nearly every crystal shows some effects of corrosion, and in many cases the plagioclase is replaced by myrmekitic intergrowths. Slight indications of corrosion by microperthite are also shown by the muscovite. A few quartz grains are enclosed in the microperthite, and the range of crystallization of the quartz appears to have been extended slightly compared with the quartz of the biotite-granite. A few flakes of brown biotite usually associated with the muscovite are present, but the other accessory, apatite, is of rare occurrence.

ANALYSIS II.

		Norm.		*Mode.*	
SiO_2	73·60				
Al_2O_3	12·65	quartz	27·90	quartz	38·5
Fe_2O_3	1·50	orthoclase	28·91	microperthite	34·0
FeO	0·64	albite	36·68	plagioclase	23·6
MgO	0·51	anorthite	0·83	muscovite	2·4
CaO	0·95	diopside	2·38	biotite	1·5
Na_2O	4·34	hypersthene	0·20		
K_2O	4·85	magnetite	2·09		100·0
$H_2O +$	0·57	apatite	0·34		
$H_2O -$	0·17	water	0·74		
TiO_2	trace				
P_2O_5	0·18		100·07		
MnO	*nil*				
	99·96				

2. Muscovite-biotite-granite. South side of Conlach Mhor. (Anal. W. A. Deer.)

The muscovite-biotite-granite of Conlach Mhor differs from the rock of the main intrusion in the development of slightly coarser grain size, and the biotite $\beta = 1{\cdot}644$ is a greenish variety with $\gamma =$ yellow green, $\alpha =$ pale yellow. In the enclosure of quartz by microperthite, the lack of idiomorphic microperthite, the intense corrosion of plagioclase and its replacement by myrmekitic intergrowths, the sericitization of the plagioclase, and the scarcity of all accessory minerals, it is identical with the main mass of muscovite-biotite-granite. An analysis of the Conlach Mhor rock is given on p. 177.

5. Intermediate Hybrids.

Close to the granite, along the eastern side of Feith an Lochain and the Allt nan Creagan Breac and to the south-east of Meall Tionail, a series of granite-diorite hybrids has been developed. The first effect of the hybridization of the diorites is a decrease in the grain size of the rock, which consists of small hornblendes and somewhat larger (1 mm. in length) plagioclase laths. The latter are hypidiomorphic, zoned from Ab_{60} ($\alpha' = 1{\cdot}547$) to Ab_{75} ($\alpha' = 1{\cdot}541$) and occur in small patches giving the rock a slightly heterogeneous appearance. The irregular grains of hornblende are strongly pleochroic with $\gamma =$ green-brown, $\beta =$ yellow-green, $\alpha =$ pale yellow. Augite occurs occasionally as small cores within the hornblende and a little biotite (up to 3 per cent.) is also present. Apatite, sphene, magnetite, and infrequent pyrite sometimes thinly rimmed with haematite are accessories. There is no mechanical addition of granitic material at this stage (anal. No. 3) and the above changes are due entirely to recrystallization of the original minerals and reciprocal reaction with the hybridizing magma. The evidence of recrystallization within the original hornblende becomes more obvious with the slightly later development of poikilitic hornblende. This recrystallization is carried further by the formation of a criss-cross texture of either hornblende or biotite flakes within the original hornblende and their gradual decrease in grain size.[1] From this initial stage a series of increasingly acid hybrids has been developed, and three stages will be described below corresponding to the other analysed intermediate hybrids (anals. Nos. 4, 5, 6).

With the commencement of acidification by granitic material the rock is still medium to fine-grained in texture and resembles the initial stages described above but with the obvious difference of conspicuous biotite. None of the constituents show idiomorphic margins and the older hornblende is gradually replaced by criss-cross aggregates of a new and smaller hornblende with $\gamma =$ brownish-green, $\beta =$ yellow-green, $\alpha =$ pale yellow-green, the recrystallization often being accompanied by the ejection of magnetite. This is well displayed where the original hornblende contains the small, later formed variety in which many grains of magnetite are enclosed. In some cases, especially towards the periphery of the aggregates, strongly pleochroic biotite, with $\gamma =$ dark mottled brown, $\alpha =$ pale yellow, becomes more abundant than hornblende. The breakdown of the hornblendes and their replacement by a new hornblende of smaller grain size has resulted from a change in the conditions of phasal equilibrium and confirms the suggestion made by Joplin,[1] that the grain-size of coarse basic plutonic rocks may be reduced during the process of hybridization. The plagioclase Ab_{58} ($\alpha' = 1{\cdot}548$) is slightly sericitized, and in contact with incoming potash felspar shows corrosion. The quartz occurs in small pools and bears no relationship either in amount or position to the developing potash felspar. This lack of a definite relationship between the incoming quartz and potash felspar has already been noted in a number of cases of hybridization similar to those described.[2] Apatite is particularly abundant at this stage in the hybridization and as long delicate needles is especially concentrated in the felspar. The other accessory minerals are zircon, sphene, magnetite, and a little epidote. The latter is associated with the interstitial quartz and appears to have been formed during the hybridization process.

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[1] Joplin, G. A., " A note on the origin of basic xenoliths in plutonic rocks with special reference to their grain-size," Geol. Mag., LXXII, 1935, 232.

Further addition of quartz and potash felspar into the hybrids rapidly changes the appearance of the rock. It then becomes coarser grained and patchy in appearance, due partly to the enclosure of darker and finer grained areas within a lighter coloured rock (anal. No. 5). Biotite ($\beta = 1{\cdot}641$) equal in amount with hornblende, slightly increases in grain size (1 mm.) and develops a deeper pleochroism with γ = dark mottled brown, α = yellow. The hornblende does not share this increase in grain size and is gradually replaced by the biotite. The plagioclase Ab_{65} ($\alpha' = 1{\cdot}545$) also increases in size and the largest crystals measure 2 mm. in length. Enclosed within this newly developing plagioclase are relics of the older, smaller plagioclase which remain as irregular altered cores surrounded by a clear periphery of new felspar. Corrosion by potash-felspar is now more extensive and small portions of the original plagioclase are often detached from the parent crystal, become small, formless, shadowy blebs and finally disappear, but in some cases reactive intergrowth is developed and the plagioclase protected from further corrosion. Occasionally the potash-felspar penetrates the plagioclase irregularly but the more usual method is either along twinning or cleavage planes. The quartz is again found as independent pools without relationship to the potash-felspar. Apatite, sphene, zircon, and magnetite are accessory.

An advanced stage in the hybridization is represented in analysis No. 6. This rock is coarser grained, and much lighter in colour than the rocks of the earlier stages. Biotite is the dominant ferromagnesian constituent and hornblende is inconspicuous in hand specimen, while quartz is easily discernible. Both biotite and plagioclase Ab_{71} ($\alpha' = 1{\cdot}543$) have increased in size up to individuals 3 mm. in length. The biotite, $\beta = 1{\cdot}642$, is very strongly pleochroic with γ = deep reddish brown, α = pale orange, and has a ferrous iron percentage of 17·99. A little alteration of the biotite to chlorite occurs, frequently preceded by an intermediate development of green biotite. Similar but more intensive effects of the plagioclase

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[1] Joplin, op. cit., pp. 227–234.

[2] Deer, op. cit., p. 54. Nockolds, S. R., "The Petrology of Barnavave," Geol. Mag., LXXII, 1935, 297.

ANALYSIS III–VI.

(Granite-diorite hybrids.)

	3.	4.	5.	6.
SiO_2 . .	50·42	49·23	54·87	64·13
Al_2O_3 . .	18·41	21·47	18·17	17·09
Fe_2O_3 . .	2·17	2·57	2·70	1·98
FeO . .	4·93	6·74	4·65	2·81
MgO . .	6·09	4·43	3·70	1·61
CaO . .	10·11	6·17	6·17	3·49
Na_2O . .	3·31	3·14	3·99	3·76
K_2O . .	1·05	1·76	2·14	3·14
H_2O + . .	1·07	1·06	0·83	0·69
H_2O – . .	0·40	0·20	0·09	0·19
TiO_2 . .	1·47	2·09	1·25	0·78
P_2O_5 . .	0·47	0·69	0·30	0·27
MnO . .	0·36	0·15	0·13	0·04
CO_2 . .	—	—	0·36	—
S . .	—	—	0·68	—
Cr_2O_3 . .	—	—	trace	—
	100·26	99·70	100·03	99·98

Norms.

	3.	4.	5.	6.
quartz . .	—	2·16	5·10	20·04
orthoclase .	6·12	10·52	12·79	18·35
albite . .	27·77	26·72	34·06	31·96
anorthite .	32·23	26·41	25·02	15·85
corundum .	—	5·00	—	1·73
diopside .	11·55	—	0·89	—
hypersthene .	10·51	18·10	12·07	6·24
olivine . .	3·32	—	—	—
ilmenite. .	2·89	3·95	2·28	1·52
magnetite .	3·25	3·71	3·94	3·02
apatite .	1·34	1·68	0·67	0·67
calcite .	—	—	1·00	—
pyrite . .	—	—	1·68	—
water . .	1·47	1·26	0·92	0·88
	100·45	99·51	100·42	100·26

Modes.

	3.	4.	5.	6.
quartz . .	2·6	5·3	6·8	11·5
orthoclase .	—	4·8	6·9	12·8
plagioclase .	49·1	50·3	49·6	54·8
hornblende .	41·9	24·4	19·1	2·0
biotite . .	3·0	15·2	16·1	18·9
accessories .	3·4	—	1·5	—

3. Intermediate hybrid. 400 yards north of the head of Feith Uaine Bheag.
4. Intermediate hybrid. Head of Allt nan Creagan Breac.
5. Intermediate hybrid. West of Feith an Lochain.
6. Intermediate hybrid. 700 yards north-east of Forest Lodge in River Tilt.

(Analyst for anals. 3–6: W. A. Deer.)

corrosion displayed in the earlier stages of the hybridization are seen, and there is also the further development of indefinite patches of potash-felspar occurring within the plagioclase boundaries. The orthoclase now forms large irregular plates frequently completely enclosing a number of plagioclase laths, and quartz occurs in interstitial areas of considerable size. Apatite, zircon, and magnetite occur as accessories but there is very little sphene, which is probably due to the titaniferous nature of the biotite. The antipathetic relationship of biotite and sphene in rocks of this type has already been noticed by Nockolds.[1] If the whole of the titania in the rock is taken up by biotite it would contain approximately 4 per cent. TiO_2, which is not uncommon in biotites of intermediate and acid rocks.[2]

6. Acid Hybrids.

Nockolds[3] has recently pointed out two different methods of producing contaminated granites or acid hybrid rocks, and for these he has introduced two new terms, exocontaminated and endôcontaminated. The first is used to define rocks in which the incorporation of material is due largely to mechanical disintegration of xenoliths and the scattering of the mineral phases in the assimilating host, and the second includes rocks whose composition is, in the main, the result of reciprocal reaction with xenoliths. Between these two types falls the group of normal contaminated rocks in which the composition is the result of a combination of these two processes acting together. Examples of these three types of acid hybrid rocks have been recognized in the contaminated granites of the Glen Tilt intrusion.

The exocontaminated type is best seen to the east of the intermediate hybrids on the west side of Feith an Lochain. Here they are fine-grained rocks with slightly coarser patches and are penetrated by later granitic veins which are themselves often slightly hybridized. The hybrid is somewhat dark in colour due to the small grain size of the felspars and the uniform distribution of the biotite. In thin section it is distinguished from the granites by the slight predominance of plagioclase Ab_{80} ($\alpha' = 1{\cdot}539$) over microperthite, less quartz, a higher percentage of biotite, and relic cores of incorporated plagioclase surrounded by rims of more acid plagioclase. The allotriomorphic microperthite occupies large interstitial areas and although enclosing many plagioclase laths corrosion effects are slight. The biotite $\beta = 1{\cdot}642$, occurs in small well-developed flakes, often in uniformly spaced aggregates of ten to fifteen individuals, with γ = greenish brown, α = pale yellow. Apatite within the felspar and sphene are abundant accessories, orthite is also present but magnetite is almost absent. The intrusion of later granite veins appears to have taken place after complete consolidation of the hybrid but while the latter was at a high temperature. The contact is never sharp but grades over a transition zone of approximately 2 inches in width. This zone appears to be too small to support the supposition that the hybrid was still incompletely crystallized when these later granite veins were injected.

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[1] Nockolds, op. cit., p. 442.

[2] Deer, W. A., "The composition and paragenesis of the biotites of the Carsphairn Igneous Complex," *Min. Mag.*, xxiv, 1937, 495–502.

[3] Nockolds, S. R., "Contributions to the Petrology of Barnavave, Carlingford, I.F.S. I: The Junction Hybrids," Geol. Mag., LXXII, 1935, 303.

Normal contaminated types are most common, and form the main part of the eastern side of the upper Feith an Lochain. These rocks are lighter in colour but similar in grain size to the exocontaminated granites. The microperthite shows a subporphyritic development and the rocks strongly resemble the acid hybrids of Carsphairn.[1] No heterogeneity is apparent and most of the constituents are less than 0·5 mm. in length and the biotite is usually smaller. The plagioclase and biotite are hypidiomorphic in form, but the microperthite, except in the porphyritic individuals, is allotriomorphic and together with the quartz, which is granular in texture, shows an interstitial relationship to the plagioclase Ab_{82} $(\alpha' = 1{\cdot}538)$. The contact between the microperthite and plagioclase is often marked by myrmekitic intergrowth, and some of the smaller laths are completely replaced by myrmekite. The microperthite is again characterized by the enclosure of small plagioclase laths but corrosion effects and the gradual disappearance of the plagioclase are not very marked. This is contrasted with the exocontaminated types, and is correlated with the development of a more stable plagioclase, made possible by an undoubted greater fluidity of the rock before its final crystallization. Quartz grains are enclosed within the microperthite, and the quartz as in the uncontaminated granite shows a somewhat earlier crystallization range than the potash felspar. No hornblende is present, but some biotite, $\beta = 1{\cdot}685$, and pleochroic from γ = mottled brown to α = pale yellow, occurs. An analysis of this type is given below.

ANALYSIS VII.

		Norm.		*Mode.*	
SiO_2	69·26				
Al_2O_3	16·64	quartz	27·18	quartz	23·5
Fe_2O_3	1·14	orthoclase	21·68	microperthite	36·2
FeO	1·41	albite	33·01	plagioclase	34·4
MgO	1·06	anorthite	7·51	biotite	5·9
CaO	1·76	corundum	3·47		
Na_2O	3·92	hypersthene	3·79		100·0
K_2O	3·68	ilmenite	0·61		
H_2O +	0·47	magnetite	1·62		
H_2O −	0·09	apatite	1·34		
TiO_2	0·31	water	0·56		
P_2O_5	0·60				
MnO	0·07		100·77		
	100·41				

7. Acid hybrid. 100 yards east of Feith an Lochain. 1,500 yards from the junction with the Allt nan Creagan Breac. (Anal. W. A. Deer.)

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[1] Deer, W. A., op. cit., pp. 49–51.

The clearest example of an endocontaminated rock is seen in the granite above Forest Lodge. Here no trace of diorite or fine-grained acid hybrid xenoliths has been found in the granite, but towards the contact with the diorite the granite becomes more basic without any decrease in grain size. This condition appears to be due entirely to the incorporation of fresh material derived by reciprocal reaction from the diorite with the consequent precipitation of phases slightly more basic than in the normal granite. This is marked by a greater concentration of biotite and an increase in the amount of the plagioclase, Ab_{75} ($\alpha' = 1·541$), as well as in the percentage of the anorthite molecule of the felspar. These rocks are coarse-grained, homogeneous, and pale yellow in colour, and there are no indications, such as relic plagioclase laths, of any material being derived by mechanical incorporation from diorite xenoliths. Its present composition represents a slightly modified acid magma, with the consequent crystallization of somewhat more basic phases than in the unaffected granites.

Although no analysis of the uncontaminated granite of these patches of acid rock along the north-eastern strip of the intrusion has been made, the rocks differ only slightly from the analysed specimen of the Sron a'Chro' granite, and some indication of the movement of oxides can be estimated by a comparison of the analyses of the quartz-diorite[1] (No. 9), the endocontaminated granite (No. 8), and the uncontaminated granite (No. 1).

ANALYSES VIII AND IX.

	1.	8.	9.
SiO_2 .	69·12	68·05	52·33
Al_2O_3 .	15·99	16·26	21·23
Fe_2O_3 .	0·94	0·51	3·54
FeO .	1·38	1·96	4·93
MgO .	1·25	1·41	2·67
CaO .	2·16	4·01	6·98
Na_2O .	4·62	3·21	3·01
K_2O .	3·81	3·12	1·82
H_2O+ .	0·35	0·54	1·11
H_2O- .	0·11	0·24	0·17
TiO_2 .	0·46	0·54	1·76
P_2O_5 .	0·23	0·08	0·69
MnO .	0·01	0·05	0·07
	100·43	99·98	100·31

	Norms.	
	8.	9.
quartz .	25·74	9·60
orthoclase .	18·35	10·56
albite .	27·25	25·15
anorthite .	19·74	30·30
corundum .	0·41	3·26
hypersthene	5·88	10·26
ilmenite .	1·07	3·34
magnetite .	0·70	5·10
apatite .	0·30	1·68
water .	0·78	1·28
	100·22	100·53

1. Granite quoted from p. 176.
8. Acid hybrid (endocontaminated) quarter of a mile north-east of Forest Lodge. (Anal.: W. A. Deer.)
9. Quartz-diorite. Allt na Maraig, 400 yards from junction with the Tilt. (Anal.: W. A. Deer.)

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[1] The description of the diorites and associated appinitic rocks of the Glen Tilt Complex will be dealt with in a later paper. The general consideration of the formation of the acid rocks and the Complex as a whole will also be reserved until a later publication.

These analyses show the granite has gained FeO, MgO, and CaO from the diorite, and lost potash and soda to the diorite, which is in accordance with the well-known trend of oxide movements during the process of reciprocal reaction. Alumina remains practically unchanged, but there has been a loss in phosphorus. This feature of low phosphorus in the endocontaminated granite is in strong contrast with the normally contaminated types in which a concentration of P_2O_5 usually takes place, e.g. in the acid hybrid of Glen Tilt $P_2O_5 = 0{\cdot}60$ per cent. The endocontaminated granite from Barnavave[1] also shows low phosphorus ($P_2O_5 = 0{\cdot}02$ per cent.), while in the heterogeneous exocontaminated granite from the same intrusion the percentage is high ($P_2O_5 = 0{\cdot}46$ per cent.). This contrasted behaviour of phosphorus in the development of endocontaminated and exocontaminated granites is in agreement with the two methods of their formation. Thus the endocontaminated types should contain less phosphorus than the uncontaminated granite, as the acid rock is losing phosphorus during the reciprocal interchange with the more basic rock, whereas the exocontaminated types are gaining phosphorus during the same process. This distinction in the phosphorus percentage of contaminated granites may be of value in distinguishing between examples of endocontaminated and exocontaminated types when the other evidence is not conclusive.

REVIEWS.

EVOLUTION AND ITS MODERN CRITICS. By A. MORLEY DAVIES, D.Sc. pp. x + 277 with 30 figs. London: Murby and Co., 1937. Price 7*s.* 6*d.*

A BOOK which discusses not the how and why of evolution, but whether evolution has occurred at all, seems likely to fall between two stools; for while most zoologists and palaeontologists take evolution for granted the unspecialized general reader has scarcely the detailed knowledge to appreciate the evidence. This volume " was primarily designed as a reply to Mr. Douglas Dewar's *Difficulties of the Evolution Theory* "; Mr. Dewar apparently would admit evolution within a family but not beyond it. The conclusion by Dr. Davies that " whatever may be the difficulties of the theory of evolution, they are not solved by Mr. Dewar's proposed limitation to within the range of the Family ", would be accepted by most systematists.

Fortunately Dr. Davies has extended the scope of his book beyond his original plan; it is now largely an expression of his own ideas, rather than a rejoinder to a critic of evolution. It includes short historical summaries of old and new ideas of creation and evolution; a restatement of the imperfections of the geological record; a discussion of the relation between reptiles and birds, the origin of mammals, and the evolution of man; and in the chapter on sample families recent palaeontological work on the evolution chiefly of mollusca and mammalia is digested. But this summary of the contents scarcely does justice to the work, which bears witness to wide reading and a questioning mind. One may hazard the guess that of all his books this has given the author the most pleasure in writing.

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[1] Nockolds, op. cit., p. 304.

A. G. B.

REGIONALE GEOLOGIE DER ERDE. Band I: DIE ALTEN KERNE, ABSCHNITT V, AFRIKA. By E. HENNIG. pp. 142, with 22 text-figures and two folding tables. Akademische Verlagsgesellschaft, Leipzig, 1938. Price 22 RM.

IT may be suggested that the title of this work is slightly misleading. The expression "die alten Kerne" seems to suggest that it deals only with the geology of the most ancient rocks, in fact the Precambrian, whereas in reality it is a complete treatise on African geology from the earliest times up to the Pleistocene. This is a large order for 142 pages, and involves intense compression, thereby rendering the task of the reviewer very difficult. The only regions not dealt with are the Atlas lands and Madagascar, but Arabia is included. To be quite candid, the book is extremely tough reading, and it is difficult, while preserving due balance, to pick out points for comment. As is inevitable, the text consists very largely of correlations of the rocks of different and widely separated areas, the correlations being for the most part, and wisely, founded on tectonics, since over so much of the continent fossils are rare or non-existent, and lithological correlations are proverbially dangerous. Actually, as is well known, the earliest widespread datable formation is the Karroo system; it seems a little old-fashioned to assign the Dwyka to the Permian. Most authorities now appear to agree that it is Upper Carboniferous and possibly well down in this.

Some other correlations are also open to criticism. It will perhaps be most interesting to English-speaking geologists to consider briefly some points connected with the stratigraphical series in the Union of South Africa. Here in the Western Province of Cape Colony, we have the earliest known really definite and well-developed fauna of the southern part of the continent, in the undoubtedly Devonian Bokkeveld beds, which unfortunately are only found over a very small area and never more than about 100 miles from the coast, which for Africa is a mere fringe. Below these, quite conformably, comes 5,000 feet of Table Mountain Sandstone, which may therefore extend down into the Silurian. At Table Mountain this rests horizontally on the strongly folded Malmesbury series with its wonderful displays of contact metamorphism by the Table Mountain granite, and complete absence of fossils where not metamorphosed. This is now generally correlated with the Transvaal system, on the ground of the presence of dolomite in both. In his large correlation table, plate i, Dr. Hennig assigns most if not all of this to the Cambrian. One would like to see the fossils on which this is based. Furthermore, in the Transvaal, above the Transvaal system, comes the enormously thick Waterberg system, also entirely unfossiliferous, here assigned to the " Lower Silurian ", which may or may not mean Ordovician. Now this Waterberg system consists of the usual type of obviously terrestrial red sandstones and conglomerates so characteristic of the latest Precambrian (Algonkian) in many parts of the world. It is to be noted that the Waterberg is separated from the Transvaal system by the great igneous episode that includes the Bushveld complex, and by the Younger Neo-africide fold-system of our author's classification. On these grounds some hesitation may be felt in accepting the correlations here given with the older Palaeozoic systems of Europe and America.

From want of the requisite local knowledge no attempt will be made here to criticize the author's correlations of the formations developed in South-West Africa, Rhodesia, the Congo, Tanganyika, etc. It may, however, be of interest, since the author's outlook is commendably and frankly tectonic, to give a very brief summary of his divisions of periods of diastrophic upheaval, in the form of a list, referring to the formations recognized in the Union as a time-scale. Proto-africides, between the Swaziland and the Barberton; Meso-africides, at the base of the Witwatersrand system; Older Neo-africides, between the Ventersdorp and the Black Reef; Younger Neo-africides, between the Rooiberg and the Waterberg; Griquaides (of subsidiary importance) between the Waterberg and the Cape system; Capides, at the top of the Karroo system, i.e. the Cape Fold Ranges, with intrusion of the Karroo dolerites, following the Stormberg lavas, and (slightly later) the Lebombo flexure. Space will not here allow of a discussion of the Rift Valley system and its accompanying vulcanicity.

Probably the most important part of the whole book is the small tectonic structural map on p. 123.

R. H. R.

REPORTS AND PROCEEDINGS.

Mineralogical Society.

27th January, 1938.

(1) "The paragenesis of a Malvern hydrobiotite, and the variable content of hydroxyl in micas generally." By Professor A. Brammall, Mr. F. A. Bannister, and Mr. J. G. C. Leech.

The hydrobiotite gives an X-ray pattern normal for biotite. On the basis of (O, OH, F) = 48, (OH) = 13·70, and (KNa) = 0·93, its constitution is compared with that of three hydromuscovites, two normal biotites, and a lithionite from Trelavour Down, Cornwall. Dehydration data are given, and experimental work on the hydrolysis of these micas was briefly demonstrated.

(2) "Curvature in crystals of vein-quartz." By Dr. A. T. J. Dollar.

Genetic problems presented by curved and fractured quartz crystals, closely associated with straight and unfractured crystals of the same mineral, are discussed in relation to anomalies of their surface form and internal optical properties. The specimens were derived from a vein in the slates of Lundy Island, Bristol Channel.

(3) "A petrographic description of lundyite from Lundy Island, Bristol Channel." By Dr. A. T. J. Dollar.

Lundyite was named by T. C. F. Hall in the Summary of Progress of the Geological Survey of Great Britain for 1914. Two chemical analyses have been made and details of the petrography are brought forward.

(4) "The Kaalijärv meteorite from the Estonian craters." By Dr. L. J. Spencer.

The crater-lake of Kaalijärv on the island of Oesel was first described in 1827, and many suggestions have been made as to its mode of origin. A detailed survey, with excavations and borings, of this and of five other smaller craters was made by Mr. I. Reinvald in 1929 and 1932, and he was convinced of their meteoritic origin, although no trace of meteoritic material could be found. With remarkable persistence he returned to the work of excavation in July, 1937, when he was rewarded by finding thirty small fragments of much rusted meteoritic iron with a total weight of about 100 grams. A polished and etched section of one piece shows much schreibersite in an ataxite groundmass, the latter containing 8·32 per cent of nickel. The meteoritic origin of these craters is therefore now established.

Dr. C. E. Tilley exhibited lamprophyllite from the Kola peninsula and molengraaffite from Pilandsberg, Transvaal, and gave evidence to prove the identity of the two species.

10th March, 1938.

(1) Tabular spessartite crystals in muscovite. By Professor E. D. Mountain and Mr. Leslie E. Kent.

In a quartz-albite pegmatite at the Union Mica Mine, south of the Murchison range in N.E. Transvaal, garnet crystals flattened parallel to 110 face occur in muscovite "books" parallel to the cleavages. The garnets among themselves have no well-defined orientation but sometimes occur in rows parallel to growth-planes of the muscovite. The crystallization of mica and garnet seems to have been more or less simultaneous, the partially crystallized muscovite influencing the habit of the garnet by molecular forces.

(2) On the nature of withamite. By C. Osborne Hutton.

The pink epidote mineral, withamite, occurring in altered andesites in Glen Coe, Scotland, has been analysed and its optics determined. This data shows that it is a poorly manganiferous piedmontite with a pleochroism comparable to that recorded for the New Zealand mineral. The occurrence is compared with several piedmontite-bearing localities in America and two hypotheses as to origin are put forward.

(3) Australites: a unique shower of glass meteorites. By Dr. Charles Fenner.

The different types of tektites and the several theories of their origin are reviewed. The similarity of type and the wide distribution of australites point to a cosmic origin. It is suggested that they were shed from a meteoritic body in the earth's atmosphere as siliceous blobs, which on further melting during flight acquired their particular shapes.

(4) The stilpnomelane group of minerals. By C. Osborne Hutton.

Stilpnomelane minerals have been found, often abundantly developed, in the low grade, dynamically metamorphosed schists of Western Otago, New Zealand. Their chemical and optical properties have been studied and the relationship between them has been represented by curves. These minerals are found to vary between end members, the hydrous ferric silicate, stilpnomelane, and the hydrous ferrous type, for which the name ferrostilpnomelane is proposed, and a manganiferous member, parsettensite. Six new analyses of members of the group and seven rock analyses are given, while the results of dehydration and X-ray work are also submitted. A theory of metamorphic origin of members of the group is advanced.

(5) An account of British mineral collectors and dealers (continued). By Mr. Arthur Russell.

(6) The rare-earth content of the fluorite of England and Wales. By V. L. Aspland, A. Brammall, and J. G. C. Leech.

Quantitative spectrographic analyses of these fluorites for elements cerium (Ce_{58}) to lutetium (Lu_{71}) have been made; and the significance of their distribution in relation to petrographic and metallogenetic provinces is discussed.

CORRESPONDENCE.

INTERNATIONAL GEOLOGICAL CONGRESS, 1940.

Sir,—As Chairman of the Excursions Committee I should welcome any suggestion. Individual excursions will last from ten to twenty-one days. The immediate object is selection rather than organization.

E. B. Bailey

Geological Survey and Museum,
Exhibition Road,
South Kensington,
London, S.W. 7.
11th March, 1938.

A DYKE SWARM IN EAST GREENLAND.

Sir,—In connection with the important dyke swarm recorded by Messrs. L. A. Wager and W. A. Deer in the January number of the Geological Magazine, it is striking to find the attendant phenomena so closely repeating those described by the writer for the meridional Lebombo monocline of the Eastern Transvaal.[1] There a basic swarm cuts, though not exactly at right angles, a thick group of lavas dipping seawards, and seemingly represents the feeder system to the upper effusions. The dykes become more numerous as the dip of the flows increases, and were introduced during the outpouring and downbending of the volcanics under considerable east-west tension.

The evidence cited by Wager and Deer incidentally constitutes strong support for the drifting of Greenland away from Scandinavia during the Tertiary with extensive downwarping, fracturing, and intrusion along the margin of the block.

It is unnecessary, however, to assume a deep-seated migration of sial towards the continent, as proposed by the authors, since the acceptance of the "paramorphic principle", developed elsewhere by the writer,[2] will readily explain both the super-elevation of the interior of Greenland and the sinking of the adjacent ocean floor. Their instructive paper provides, as a matter of fact, no small measure of support for that particular hypothesis of mineral transformation of a paramorphic nature in the sub-crust through loading and unloading of the earth's surface.

Alex. L. du Toit.

P.O. Box 4565,
Johannesburg.
14th February, 1938.

FLUORSPAR AND BARYTES IN THE NORTHERN PENNINES.

Sir,—A point of some general interest was raised by Mr. Arthur Russell in a discussion at a meeting of the Mineralogical Society on 11th March. In commenting on my published statement[3] that fluorspar in the Northern Pennine mineral field crystallized before barytes at the seventeen localities where those two minerals are found together, Mr. Russell stated that he has in his collection specimens from the Scordale mine, Westmorland (one of the localities in question), which show the opposite order of deposition. I was surprised at the time of my investigation of the Northern Pennine area not to be able to find any unambiguous evidence of fluorspar later than barytes, in view of the frequent interbanding of these minerals to be seen in Derbyshire.[1] Mr. Russell's observations are therefore welcomed because they show that in the Northern, just as in the Southern, Pennine field, fluorspar may sometimes follow barytes in sequence.

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[1] *Trans. Roy. Soc. S. Afr.*, xviii, 1929, 189.

[2] *Our Wandering Continents*, Edinburgh, 1937, x, xi.

[3] Dunham, K. C. "Genesis of the North Pennine Ore Deposits," *Quart. Jour. Geol. Soc.*, 90, 1934, 709.

This fact does not, of course, in any way prejudice my suggestion that the regular geographical disposition of the gangue and sulphide minerals in the area is due to temperature zoning. Mineral sequence in leptothermal deposits like those of the Pennines is notoriously unreliable on account of the common occurrence of banding ; it thus affords little guidance to the zonal relations to be expected.

The crystallization of barytes before fluorspar mentioned by Mr. Russell as occurring in some Cornish lodes in no way affects the correctness of the view that the barytes zone there represents lower temperature conditions than the fluorspar zone. Wolfram, though usually characteristic of the zone above the tin zone [2] nevertheless precedes cassiterite in order of deposition according to H. B. Cronshaw.[3] Similarly, Professor L. C. Graton has informed me that in the Butte district, Montana, sphalerite characteristic of the outer zones is sometimes found as the earliest sulphide mineral in the innermost enargite zone. This points to deposition while the temperature was rising, from which it may be suggested that barytes preceding fluorspar perhaps implies the same thing.

It follows that zoning provides the only safe guide to the temperature relations between vein minerals obtainable from field evidence. Mineral sequence at any particular place is likely to record both the rise and fall of temperature in the vein, as well as any fluctuations that may have occurred.

I should like to take this opportunity of expressing my regret that no reference was made in my 1934 paper to Mr. Russell's note recording his discovery of niccolite and ullmannite at Settlingstones.[4] The paper from which I was quoting also made no reference to this prior record.

KINGSLEY C. DUNHAM.

GEOLOGICAL SURVEY AND MUSEUM,
EXHIBITION ROAD,
LONDON, S.W. 7.

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[1] Dunham, K. C. "Paragenesis and Colour of Fluorite in the English Pennines," *Amer. Min.*, 22, 1937, 473.

[2] Davison, E. H. "Mineral Associations in Cornish Tin Lodes," *Mining Mag.*, September, 1930, 2.

[3] Cronshaw, H. B. "Structure and Genesis of some tin-lodes in the Camborne district of Cornwall," *Trans. Inst. Min. Met.*, 30, 1920–1, 467.

[4] Russell, A. "Notice of an occurrence of niccolite and ullmannite at the Settlingstones Mine, Fourstones, Northumberland, etc.," *Min. Mag.*, 1927, 383–6.

CORRELATION OF THE COAL MEASURES OF SCOTLAND AND LANCASHIRE.

SIR,—In a paper [1] on the Anthracomyas of the Lancashire Coal Measures, Dr. W. B. Wright makes a detailed correlation with the Scottish Coal Measures basing his conclusions on illustrations of Scottish non-marine lamellibranchs published by the writers.[2] The paper is welcome evidence of the dissipation of the pessimism that, eighteen months ago, infected Dr. Wright's attitude to the lamellibranch zoning of the Coal Measures.[3]

In the introduction to his paper Dr. Wright says: "They (i.e. Weir and Leitch) have identified in the Productive Coal Measures three of Trueman's northern zones, namely Ovalis, Modiolaris, and Similis-Pulchra and *one* [our italics] of the Lancashire subzones, namely that of Pseudorobusta. In making comparison with Lancashire, however, they might have gone much further than this, for eight of the established subzones of the productive measures of Lancashire are recognizable in Scotland in their proper order, namely Pseudorobusta, Os-lancis, Elliptica, Retrotracta, Affinis, Pulchra, Librata, and Atra."

It seems that in paying close attention to the figures in our paper, Dr. Wright has neglected the text, or he would surely have noticed that on p. 736, discussing the general characters of the Scottish faunas, we say: "We have thus a parallel to the succession of the Pulchra-maximum, Librata, and Atra subzones in Lancashire"; and again, on p. 735, discussing the fauna of the Kiltongue Musselband: "In fact, the *Carbonicola* assemblage recalls that recorded by Wright from Lancashire above the Trencherbone ... in a similar position at the base of the Modiolaris zone" (i.e. the Os-lancis subzone).

Dr. Wright also appears to have ignored a later communication by one of us to the discussion to which he himself contributed (*Rep. British Ass.*, loc. cit., p. 354), which deals specifically with subzones, and in which the following passages occur: "The succession of Affinis, Pulchra-maximum, Librata, and Atra subzones occurs in Lancashire and in Scottish Coalfields." Again: "In Scotland the base [of the Pseudorobusta subzone] occurs at or near the base of the Coal Measures and, as in Lancashire, it [the Pseudorobusta subzone] is followed by the Os-lancis subzone, the Modiolaris zone generally and finally by the Affinis-Atra succession."

We have, therefore, recognized six of the Lancashire "subzones" in Scotland, and not one, as Dr. Wright asserts, and were emphasizing their value at the very time that Dr. Wright was tending to deprecate them. It is true that only the Pseudorobusta subzone figured in our tables, as it is the thickest and most constant, and is conspicuous in all the Scottish Coalfields. The Pulchra subzone, for example, has been proved in only one small corner of the Ayrshire Coalfield. The Retrotracta subzone does not appear to have been mentioned by Dr. Wright until this year, and we were unwilling to claim the occurrence of the Retrotracta band on the basis of our one imperfect specimen of *C. retrotracta* ("not very typical"—Dr. Wright, p. 12), but if this is sufficient evidence for Dr. Wright, we are prepared to agree that it does occur; the homotaxial position is correct. We suggest that the evidence for the occurrence of the Elliptica subzone is even more exiguous. Dr. Wright bases his recognition of this subzone on our figure 3*k*, a *C. aquilina* (*pace* Dr. Wright), a poor specimen which differs markedly in shape from the holotype and paratypes of *C. elliptica* Wright and shows pronounced tilt of the umbonal growth lines, a significant feature that is inconspicuous in the types of *C. elliptica* and is not mentioned or illustrated in Dr. Wright's original account of the species.

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[1] "The Anthracomyas of the Lancashire Coal Measures and the Correlation of the Latter with the Coal Measures of Scotland," by W. B. Wright, *Summ. Prog. Geol. Survey for 1936* (1938), pt. ii, 10–26.

[2] "The Zonal Distribution of the Non-marine Lamellibranchs in the Coal Measures of Scotland," by J. Weir and D. Leitch, *Trans. Roy. Soc. Edinburgh*, lviii, 697–751.

[3] *Rep. British Ass. 1936* (*Blackpool*), p. 352; see also S. G. Clift, *loc. cit.*, p. 355.

Dr. Wright's conception of the Atra subzone in Scotland is rather different from ours (cf. M. Macgregor in the same *Summary of Progress*, p. 68). It seems strange that he would exclude from this subzone in Scotland the "burst" and acme of *C. atra* in the mussel-band below the Ell Coal, and would restrict the subzone to the impoverished beds with dwarf forms above the Dalserf Musselband (Central Coalfield). In our interpretation the Atra subzone encroaches on beds which Dr. Wright would refer to the Librata subzone or to his new Oblonga subzone; our conception places emphasis on the *atra*-group with its numerous individuals, rather than on the very sparse Anthracomyas of the *cymbula-librata-oblonga* group. We think that some intermingling of the subzonal faunas is not inconsistent with the conditions in which these creatures lived, and that a too rigid insistence on the exact correspondence of subzones between regions 200 miles apart is a mistake. Meantime, it is sufficiently satisfactory to have established the general equivalence of the faunal succession in the two areas.

We do not propose to take up space by replying to Dr. Wright's criticisms of some of our identifications; these and other matters, including the question of "*A. adamsi*" and the position of the Affinis subzone, will be discussed in forthcoming papers. These will have as their subject statistical variation studies on certain groups. At the stage now reached in the investigation of these lamellibranchs we believe that only such studies, accompanied by ample illustration, can achieve the greater precision in naming that is desired by all workers in this field.

JOHN WEIR.
DUNCAN LEITCH.

THE UNIVERSITY,
GLASGOW.
2nd March, 1938.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXV.

No. V.—MAY, 1938.

ORIGINAL ARTICLES.

The Evolution of the Granodioritic Rocks of the South-Eastern End of the Kopaonik Batholith, Yugoslavia.

By Gilbert Wilson.

Introduction.

THE Kopaonik batholith forms the core of the Kopaonik Mountains of South Central Serbia. It has a length of about 16 kilometres, a maximum width of about 8 kilometres, and is elongated parallel to the regional tectonic trend (N.N.W.–S.S.E.), being emplaced, after the manner of most batholiths in orogenic belts, along the crest of an elongated dome. It was originally mapped by Professor Urošević in 1904,[1] (see inset map in Text-fig. 1). In 1924 Professor Kossmat correlated the intrusion with the peri-Adriatic tonalites, which form a discontinuous series of intrusive bodies extending from Northern Italy to near Salonica. Descriptions of localized but scattered rock-types, including some from this area, were given by Zujović (1924).

Whilst engaged in mining and prospecting operations conducted by the Kopaonik Mines, Limited, of London, the present writer had the opportunity of studying the area shown in the accompanying map (Text-fig. 1), which includes the south-eastern portion of the Kopaonik batholith. Descriptions of the local geology, structure, and petrology, have already been published in Yugoslavia (Wilson, 1933); but since this initial paper appeared, supplementary analyses of the metamorphic and igneous rocks have been made, and a more detailed discussion of their petrology is now possible.

The rock-types of the batholith, occurring within the area studied, are dominantly granodioritic; closely associated with them are numerous and large aplite dykes, which lie mainly to the east of the plutonic intrusion. The sediments intruded by, and forming the metamorphic aureole of the granodiorites are all members of the

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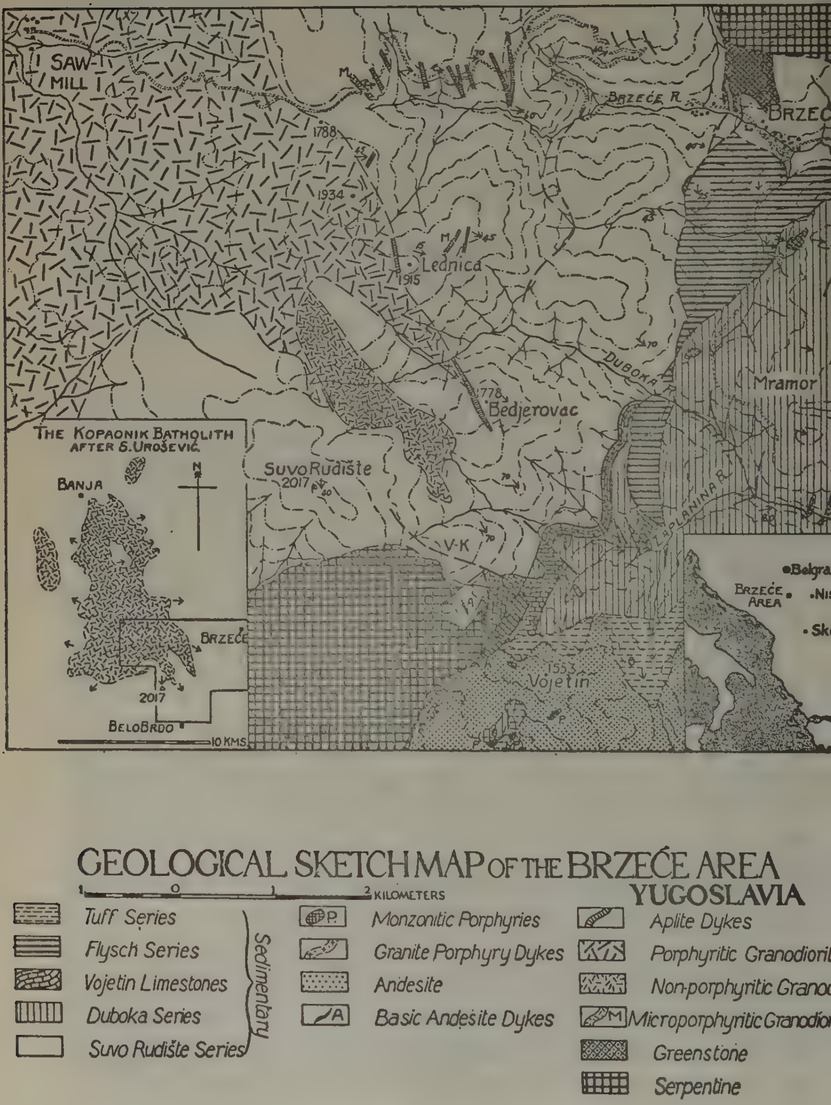
[1] A list of works to which reference is made appears at the end of the paper.

Suvo Rudište Series. Their strike swings from north-south to east-west, roughly parallel to the batholith margin; but locally the igneous rocks were observed to be in cross-cutting relationship



TEXT-FIG. 1.

to the sediments. Strike- and tear-faulting, together with isoclinal folding, have rendered the structures of this series complex, and correlation of the metamorphosed beds with their unaltered equivalents beyond the limits of the aureole has not yet been accomplished. These sediments are faulted against the Palaeozoic limestones of Mt. Vojetin in the south-east, and against (?) Cretaceous Flysch in the east near Brzeće. The latest sedimentary rocks of the area are Miocene tuffs and sandstones, which unconformably overlie all the other strata. Intrusive andesites and granite porphyries are associated with these tuffs, as are also certain serpentines. The big serpentine mass to the south of Mt. Suvo Rudište intrudes the aureole of the batholith, but is itself unmetamorphosed; it is not improbable that this serpentine also is of Miocene age. Other serpentines which have been involved in the Tertiary orogeny are considered to be Jurassic.

The geological history of the area is summarized in the accompanying table:—

AGE.	SEDIMENTARY.	IGNEOUS.
Recent.	Normal Faulting.	
Miocene	Tuffs and sandstones.	Serpentine, andesite, and porphyries.
Tertiary		Granodiorite.
	——Orogeny——	
Cretaceous (?)	Flysch sandstones, grits, and breccias.	
	——Orogeny——	
Jurassic		Serpentines and greenstones.
Palaeozoic	Duboka Series: shales, calc-shales, and sandstone. Vojetin Limestones, Suvo Rudište Series.	

THE METAMORPHIC AUREOLE.

The metamorphic aureole that surrounds the granodiorites has a width varying from 1,500 to 2,000 metres, and the rocks comprising it are, in ascending order, pelitic, calc-argillaceous, and calc-silicate hornfelses which grade to crystalline limestones and marbles. The majority fall within Goldschmidt's Classes 3 to 10. These types merge into and locally alternate with one another.

The lime-rich hornfelses of the aureole occur on the summit of Mt. Suvo Rudište, at Vratski Krš (V–K in Text-fig. 1), on the easterly slopes of Mt. Lednice, and are well exposed on the road from Brzeće to the Saw Mill. These rocks were nowhere observed in immediate contact with the granodiorite intrusions, being separated therefrom by the underlying calc-argillaceous and pelitic hornfelses.

Epidote is the first mineral to appear under conditions of low-grade metamorphism. It may be associated with chlorite, calcite, and quartz in varying proportions. With increase in metamorphism these rocks grade to epidosites on the one hand, and to diopside-rich types on the other, depending apparently on original composition. To the east and south-east of the intrusion epidote-rich and diopsidic hornfelses are commonly interbanded. Locally biotite-hornfelses alternate with these calc-silicate rocks and probably represent shaly beds in a series which consisted largely of marly types. Wollastonite is rare in the aureole; it is found in association with calcite and epidote: the original rock in this case must have been a limestone with minor amounts of clay and siliceous impurities.

Lime-garnet occurs in the higher grade metamorphic zones. It first appears as porphyroblasts in the epidosites of Vratski Krš, where the garnet-epidote-assemblage grades into idocrase-rich types (Anal. 116, Table I). Idocrase-bearing hornfelses were also found evolving from epidote-diopside types on Mt. Bedgerovac. Gehlenite was noted in one specimen from the latter locality. Other minerals seen in these calc-silicate rocks are scapolite, basic plagioclase, and magnetite. This last forms, in association with garnet, an irregular skarn deposit near the summit of Mt. Suvo Rudište.

The pelitic and calc-argillaceous hornfelses outcrop between the batholith and the more calcareous types discussed above. Pelitic types are exposed on the west side of the col between Mts. Suvo Rudište and Bedgerovac, on Mt. Lednice, and near Point 1788. Similar types occur interbanded with more calcareous rocks in the upper Zaplanina basin. Cordierite-biotite-hornfelses (Anal. 24, Table I) are the most common, and their evolution seems to have followed normal trends. Muscovite-biotite-quartz types were found near the eastern margin of the batholith. The persistence of muscovite relatively close to the intrusion is of interest: early formed sericite has not broken down into orthoclase and an aluminium silicate, rather it has recrystallized to larger units. The rock thus appears to be an arrested stage of granitization of the sediment as described by Williams (1934).

The upward gradation of the pelitic types into the calc-argillaceous hornfelses is gradual and accompanied by interbanding of the two facies to a considerable extent. This results in a rock group which comprises cordierite-biotite, biotite, amphibole-biotite, and amphibole-epidote-biotite types.

The main calc-argillaceous types are characterized by the absence of cordierite, and the incoming of amphibole. They are confined to the basin of the upper Zaplanina river, where they surround and lie above the southward-pitching nose of the plutonic intrusion. Analyses of two typical specimens are given: Anals. Nos. 130 and 225, Table I. These rocks show the impress of two metamorphic processes: an earlier low-grade dynamic metamorphism, and a later thermal metamorphism. In some cases the orientation of the minerals suggests that the two processes overlapped to a certain extent. The earlier dynamic metamorphism shows in the outer parts of the aureole, where the rocks are poorly foliated chloritic and calcic phyllites. Within the aureole these rocks are more coarsely banded, biotitic rather than chloritic, with amphibole developing in the more calcareous layers. Epidote is also present. The amphibole first appears as radiating clusters of actinolite, in which :—

X . very pale green to yellowish green.
Y . pale green.
Z . green with a bluish tinge to blue-green.
$X \wedge c$ 15°.

Table I.

Analyses of Aureole Hornfelses, from the Kopaonik Mountains.

No.	24	130	225	116
SiO_2	63·17	49·07	56·84	39·74
Al_2O_3	14·85	16·59	16·23	12·68
Fe_2O_3	1·21	1·60	1·14	8·31
FeO	6·82	7·26	5·97	2·87
MgO	4·61	8·39	4·69	1·59
CaO	1·55	6·02	5·28	31·27
Na_2O	1·35	1·69	1·58	none
K_2O	2·53	6·31	5·79	0·21
$H_2O +$	1·36	1·09	0·95	0·10
$H_2O -$	0·21	0·18	0·11	0·12
CO_2	none	none	none	0·47
TiO_2	0·72	0·75	0·96	0·83
P_2O_5	0·21	0·22	0·22	0·12
Cl	nd.	nd.	nd.	tr.
F	1·70	nd.	nd.	nd.
S	nd.	nd.	0·24	tr.
MnO	0·11	0·18	0·15	1·60
SrO	nd.	nd.	nd.	none
BaO	0·04	0·13	none	tr.
Li_2O	nd.	nd.	nd.	none
Less O	0·71	—	0·09	—
Total:	99·73	99·47	100·06	99·91

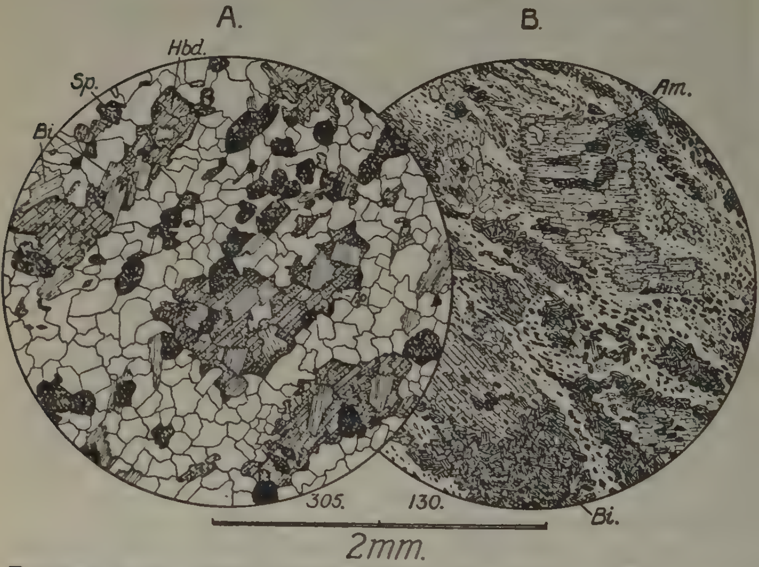
No. 24. Quartzose biotite-cordierite-hornfels, from the col between Mts. Suvo Rudište and Bedjerovac.
No. 130. Amphibole-biotite-hornfels, from the bed of the upper Zaplanina Creek, N. 10° E. of Mt. Suvo Rudište signal (2017).
No. 225. Biotite-amphibole-hornfels, from the headwaters of the Zaplanina Creek, 1,100 metres S. 78° E. of Mt. Suvo Rudište signal.
No. 116. Idocrase-epidote rock, from Vratski Krš, the south-easterly spur of Mt. Suvo Rudište.
Analysis No. 116, by Dr. H. L. Ridley; the remainder by Dr. A. W. Groves.

Nearer the intrusion this mineral occurs in small prisms, between the biotite-rich bands of the hornfelses. With further reconstitution glomeroblastic aggregates are formed which locally grow across and enclose portions of the biotite-rich layers, at the expense of which the amphibole develops (Text-fig. 2, B). The amphibole of these aggregates is in general paler in colour than the low-grade variety. Typical specimens show the properties :—

(1) X . nearly colourless
Y . very pale green.
Z . pale green to bluish green.
$Z \wedge c$ 17°.

(2) X . colourless.
Y, Z . colourless to very pale green. The greenish colour is often most pronounced around included biotite flakes in the amphibole.
$Z \wedge c$ 19°.

γ' on cleavage flakes varies from 1·652 to 1·655.



Text-fig. 2.—A. Highly metamorphosed sedimentary xenolith in granodiorite, showing green hornblende (Hbd) carrying inclusions of biotite (Bi), all in a quartz-feldspar groundmass. Sphene (Sp), apatite (Ap). B. Amphibole-biotite-hornfels from the upper Zaplanina basin, showing the development of amphibole (Am) at the expense of biotite (Bi), flakes of which it encloses.

The range of the γ' determinations is suggestive of actinolite, but as the colours observed are very pale, the mineral appears rather to be transitional towards pargasite. The increase in depth of colour noted around included biotite flakes argues enrichment in iron, probably Fe''', with possibly some Al; and the marked bluish tinge of many of the crystals is indicative of appreciable Na-content, which alone would remove the mineral from the narrow tremolite-actinolite field.

Several specimens of these amphibole-hornfelses contain porphyroblasts of albitic feldspar. Usually the mineral can only be distinguished under the microscope, but in one case from the bed of the Zaplanina river the hand-specimen appeared to be an altered porphyry, and its sedimentary origin was only definitely determined on microscopic examination. The presence of such porphyroblasts in rocks which are normally potassic is suggestive of local penetrations of the hornfelses by sodic emanations associated with the intrusion of the granodiorites, which are themselves sodic in character. The high soda/potash ratio which is found in the hornfelses immediately contiguous to the intrusion (Text-fig. 6, points 148, 143) supports this hypothesis.

The confinement of the amphibole-bearing hornfelses to the upper Zaplanina basin is itself a point of interest. Under conditions of high-grade metamorphism one would expect such types to have been converted to diopside-bearing hornfelses (Harker, 1932, p. 86). Diopsidic types do occur close to the contact on the east side of the intrusion; but in the limited area of the basin they not only fail to appear, but the amphibole-bearing types continue up to the margin of the batholith itself. The fact that this mineralogical anomaly occurs in the immediate vicinity of the nose of the batholith, here observed to be dipping southwards under the hornfelses concerned, suggests that the formation and stability of the amphibole was due to hydrous or hydroxyl-bearing emanations from the igneous mass below. That sodium was also present in the emanations is indicated by the presence of albite porphyroblasts, and it is probable that this element played an important part not only in the evolution of the amphibole, but also in the destruction of the biotite which is associated with it.

The ultimate product in the metamorphism of the amphibole-biotite-hornfelses is to be seen in xenoliths in the granodiorite. Many of these retain their granulitic character, and one still shows its original textural parallelism of light and dark minerals (Text-fig. 2, A). Here complete recrystallization of the amphibole has occurred, and it is now present as green hornblende, having the following properties:—

X . yellowish green.
Y . olive green.
Z . olive green.
$Z \wedge c$ 20°. γ' . 1·660 ± ·001.

The mineral locally shows good crystal outlines, but still carries inclusions of biotite, quartz, feldspar, and sphene, etc., which were enclosed during its porphyroblastic growth.

THE GRANODIORITES.

Petrography.

Within the area studied the granodiorite batholith is found to be a composite intrusion. It consists of three main rock-types:

porphyritic granodiorite, non-porphyritic granodiorite, and micro-granodiorite, in order of increasing basicity, together with aplites, and certain monzonitic facies, which latter are mostly marginal types. The gradation of these marginal rocks—texturally, mineralogically, and chemically—into the main granodiorites suggests that the suite as a whole is largely of mixed origin. Analyses are given in Table III.

Porphyritic Granodiorite.

This rock-type forms by far the greater part of the Kopaonik batholith. In the typical hand-specimen (Anal. No. 308) it shows coarse granitic texture with large twinned perthitic orthoclase phenocrysts up to 6 cm. in length. The groundmass crystals range up to 5 mm. grain-size. Hornblende is the dominant ferro-magnesian mineral, biotite is scarce. Yellow sphene can easily be distinguished. Under the microscope the plagioclase is seen to vary from acid-andesine to acid-oligoclase; it shows complex zoning in which corroded and cracked crystal cores are common. Perthitic orthoclase and quartz are also present in the groundmass of the rock, locally they are intergrown. Hornblendes are green in colour throughout, but their optical properties are not altogether uniform. In general they are:—

X . pale brownish green.
Y . green.
Z . green to olive green.
$Z \wedge c$ 23°. γ . 1·659 to 1·663.

Rarely these crystals contain a few biotite flakes, usually altered to chlorite. The alteration of such enclosed biotite to hornblende has also been noted. Biotite unassociated with hornblende occurs, but only in widely scattered crystals. Other inclusions in the hornblende are quartz, feldspar, apatite, sphene, and in one case epidote. Accessory minerals in the rock are apatite, sphene, titaniferous iron ore, and zircon.

Non-porphyritic Granodiorite, and its Marginal Modifications.

The non-porphyritic granodiorite (Anal. No. 227) is exposed at the extreme southern end of the batholith, and as xenoliths in the porphyritic type (Anal. No. 311). The western boundary of the intrusion follows the contour trend in a marked degree. It thus appears that the sediments lying to the east of the fault parallel to the ridge of Mt. Suvo Rudište are partly overlying the intrusion. Hence only the upper parts of the igneous mass are exposed in the window formed by the headwaters of the Zaplanina and Duboka rivers. The eastern margin of the intrusion is nearly vertical; and the southern end was observed to dip outwards at about 50 to 60 degrees.

Petrographically the rock is similar to the groundmass of the porphyritic granodiorite, except that it contains more interstitial orthoclase, which locally appears to be replacing plagioclase. Biotite is also more common. It occurs as inclusions in hornblende, and also in scattered crystals and flakes up to 5 mm. in diameter. The green hornblende has the following optical properties :—

X . light brownish green.
Y . green.
Z . green.
$Z \wedge c$ 20°. γ' . 1·659 ± ·001.

Towards the margin, particularly where it is well exposed in the headwaters of the Zaplanina, the granodiorite becomes darker in colour and finer in grain. Zoned plagioclases are often enclosed in orthoclase giving the rock a monzonitic texture. Biotite is more common than in the central portions of the mass ; hornblende is more ragged, and is irregularly distributed around clots of biotite flakes (Text-fig. 4, A). Reaction amphibole sometimes occurs at the edges of isolated biotite crystals. Analysis No. 221 is made from this marginal monzonitic facies of the intrusion.

The contact between the granodiorite and the sediments is marked by an intrusive breccia, in which the incorporation of hornfelsic material by the igneous mass can be observed both in the field and under the microscope. The fragments consist of biotite- and amphibole-hornfelses which are undergoing recrystallization and mechanical disintegration. They gradually disappear between 2 to 5 metres from the unbrecciated hornfelses.

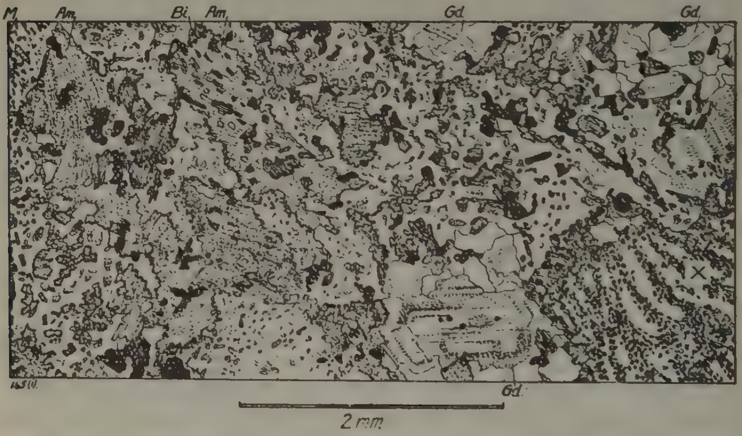
The matrix of the breccia has a mixed origin, in that it is formed by both igneous and hornfelsic material (Text-fig. 3). The latter is derived from the hornfelses by recrystallization and reconstitution. This involves, firstly, the disappearance of the banding of the hornfelses, and secondly a remarkable development of amphibole in large poikilitic aggregates containing inclusions of biotite, feldspar, epidote, quartz, and iron ore. Scattered smaller flakes of amphibole also occur ; these show a tendency to coalesce, thus forming minor individual aggregates, or increasing the bulk of the larger masses. The amphibole of this marginal mixed zone shows slight colour variations in which—

X . pale green, pale yellow green to very pale brown.
Y . green.
Z . green, bluish green to deep bluish green.
$Z \wedge c$ 19°, 2V=90°, and γ' . 1·656±·001

In one slide isolated and cracked crystals of diopside were observed ; this is the only case of this mineral occurring in the granodiorites save for a small xenolith of diopside-scapolite-garnet-rock which was seen in the microgranodiorite.

Biotite in this contact-zone behaves in a remarkable manner : small isolated crystals tend to disappear, being converted by reaction to amphibole. Where, however, the crystals are more robust, and the ratio of surface area to volume correspondingly reduced, the mineral persists, though locally reaction-amphibole may develop on its margins. Alkali determinations of this mixed marginal zone and contiguous hornfelses show preferential enrichment in soda as compared to the more central portions of the intrusion (Points 143, 148, 149, and 150, Text-fig. 6). This supports the suggestion (p. 199) that in the presence of sodic solutions biotite is unstable, and will become contributory to amphibole.

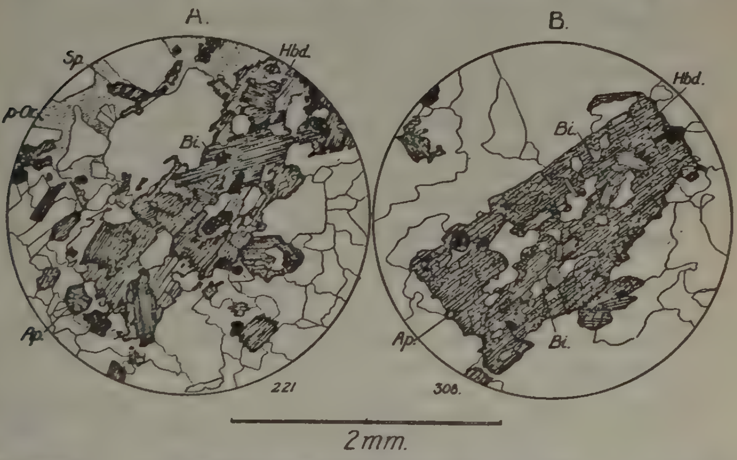
Small xenoliths of micaceous hornfels in the intrusion breccia (X in Text-fig. 3) tend to recrystallize to biotite-quartz-feldspar rock, which upon disintegration, or even recrystallization if sufficiently complete, yields minerals and rock-types not distinguishable from those of presumed igneous origin. The quartzo-feldspathic material of the reconstituted hornfelses shows an increase in grain-size, and gradually merges into the granodiorite.



TEXT-FIG. 3.—Marginal breccia immediately contiguous to the hornfels contact: (*M*) marginal hornfels; (*Am*) large plates of amphibole developing from the hornfelsic material, and enclosing poikilitically biotite (*Bi*); iron ore (black); and quartzo-felspathic material. Stringers of granodiorite (*Gd*) penetrate and detach fragments of this recrystallized material. (*X*) is a small xenolith of biotite hornfels; it shows marginal recrystallization.

Stringer-like off-shoots of the granodiorite (*Gd* in Text-fig. 3) penetrate the marginal *mélange*, detaching fragments which are floated away into the intrusion. The mechanism, as it can here be studied in its penultimate stages, is small-scale piecemeal stoping of reconstituted sedimentary material. Disintegration of these detached masses has resulted in the launching of xenocrysts into the "magma". Of these xenocrysts quartz, feldspar, and biotite are indistinguishable from such (?) magmatic material as was already there, epidote and pyroxene disappear, in the case of the latter by reaction, whilst the former seems to be just dissolving, no definite reaction being observed. Such solution would cause a late enrichment of magmatic fluids in lime.

The amphibole, however, which has grown in the hornfelses, or by reaction at the margin, persists. It is characterized by its sponge-like texture and its inclusions of quartz, feldspar, sphene, apatite, and particularly biotite. With increase in distance, from the margin the xenocrystic amphibole aggregates recrystallize and coalesce. Ragged hornblende crystals in which inclusions occupy much space, such as described from the monzonitic facies of the non-porphyritic granodiorite, are thus produced (Text-fig. 4, A).



Text-fig. 4.—A. Partially recrystallized hornblende (*Hbd*) of xenocrystic origin, in monzonitic facies of granodiorite. Poikilitic orthoclase (*p-Or*); sphene (*Sp*); and apatite (*Ap*). Plagioclase and quartz are undifferentiated.

B. Similar to (A) but considerably further recrystallized showing the development of euhedral form and the elimination of inclusions as the crystal becomes more robust.

Further recrystallization of these hornblendes yields robust crystals. such as occur both in this, and the porphyritic granodiorite (Text-fig. 4, B). This progressive recrystallization of these minerals is accompanied by the gradual absorption of their inclusions, particularly biotite, so that in the more euhedral crystals the spongy texture may be largely eliminated.

Summarizing: the various facies of the non-porphyritic granodiorite grade into one another, from typical granodiorite to monzonitic granodiorite, and thence to marginal mixed rocks. Throughout these three gradational types is a recognizable and characteristic mineralogical feature: green hornblendic amphibole poikilitically enclosing minerals normally later in the reaction series. This feature is seen to be directly inherited from the marginal hornfelses and the reaction between them and the igneous mass.

Microgranodiorite.

Microgranodiorite (Anal. No. 187) occurs in two dykes cutting the metamorphosed sediments near the eastern margin of the main intrusion. The rock is fine grained and greenish in colour, strongly reminiscent of the marginal facies of the non-porphyritic granodiorite. Under the microscope it is seen to contain small zoned plagioclase phenocrysts up to 3 mm. in length, with acid-oligoclase cores. Groundmass feldspars vary from andesine to oligoclase, and are associated with orthoclase and quartz, which are locally intergrown. Both biotite and hornblende are present as ferromagnesian constituents. The former occurs as small crystals, flakes, and glomeroporphyritic aggregates; it is in excess of hornblende. Most of the amphibole in the rock is in the form of ragged anhedral wisps and aggregates, in which flakes of biotite are usually to be observed. Rarely the hornblende is more robust and twinned on (100); such euhedral varieties, however, also carry numerous inclusions amongst which biotite again predominates. The hornblende has the following properties :—

X . very pale yellowish green.
Y . olive green.
Z . olive green.
$Z \wedge c$ 22°, 2V large, γ'. 1·658 to 1·659.

Apatite, sphene, titaniferous magnetite and leucoxene are accessory.

Quartz-Monzonite.

Quartz-monzonite, (Anal. No. 310) apart from that which occurs as a gradational facies of the non-porphyritic granodiorite, forms sub-gneissose bands in the porphyritic granodiorite. These were observed in a large outcrop 1,600 metres south of the Saw Mill. The bands are coarse-grained but non-porphyritic, and are considerably richer in ferromagnesian constituents than the granodiorite in which they occur. In their immediate vicinity, however, the granodiorite does not show any impoverishment in these minerals, as would be expected if the banding were caused by local segregation into felsic and mafic fractions. The quartz-monzonites are undoubtedly types of independent origin.

Under the microscope the plagioclase of these rocks is seen to be oligoclase-andesine; zoning is uncommon, but corroded and broken cores do show in some cases. Orthoclase and quartz present features due to late consolidation, and locally myrmekite is developed. Green hornblende in large crystals up to 7 mm. in length, and enclosing biotite, quartz and orthoclase poikilitically, is the dominant ferromagnesian mineral. It has the following properties :—

X . yellowish green.
Y . olive green.
Z . green.
$Z \wedge c$ 22°.

Biotite unassociated with hornblende is rare, and occurs only as small flakes. Apatite, sphene, and titaniferous magnetite in relatively large crystals are accessory.

Aplites.

Aplite dykes are the most common of the minor intrusions intimately associated with the granodiorites. Those which traverse the country rocks to the east of the batholith form considerable masses. Dykes lying wholly within the granodiorites are narrow and irregular; they give the impression of being local "squeeze-outs" when contrasted with the large extra-batholithic intrusions which appear to have been injected from depth. Two specimens have been analysed (Nos. 89 and 152). The former was taken from the north end of the big intrusion on Bedgerovac Mountain; and the latter was collected from a dyke traversing the marginal breccia at the contact of the granodiorite and hornfels in the bed of the Zaplanina river. This second aplite was found to contain many xenocrysts of amphibole and biotite derived from the invaded marginal rocks. Under the microscope both rocks show normal features: they contain, in a finely crystalline felsic groundmass, small phenocrysts of quartz and somewhat decomposed acid plagioclase, with a few relics of hydrolyzed mica.

Small granophyric apophyses of the granodiorites are of local occurrence. They consist dominantly of intergrown quartz and orthoclase, and closely correspond with mesostatial intergrowths seen in the granodiorites. Their formation by filter-press mechanisms acting on the nearly consolidated igneous mass at late stages of crystallization (Harker, 1909, p. 323) seems probable.

Xenoliths.

Numerous xenoliths are to be found in the main granodiorites. Mineralogically they all show features closely akin to the rocks in which they are contained, and the majority appear to be approximately equivalent to the non-porphyritic granodiorite in composition. Others are more basic, ranging to quartz-diorite and diorite. In general they are finer grained than the granodiorites, some having a granulitic texture, suggestive of a hornfelsic origin. Many are characterized by large poikilitic plates of orthoclase and quartz in which are included plagioclase crystals, ferromagnesian minerals, and rarely rounded quartz grains. Similar phenomena have been noted elsewhere (Brammall and Harwood, 1932, and others). Plagioclase crystals enclosed in these later growths are corroded, and myrmekite is locally developed at their margins. The xenoliths are all hornblende-bearing, and as in the case of the granodiorite hornblendes the mineral is spongy in texture, and carries varying amounts of biotite and other inclusions. The hornblendes vary from anhedral varieties associated with biotite, to euhedral crystals in which there is no mica, and the inclusions are only quartz or feldspar. Intermediate stages have been observed which indicate that the euhedral hornblendes are the products of progressive recrystallization of the earlier anhedral crystals. This reconstitution is similar to that seen in the evolution of the granodiorites. In the later stages the hornblende of the xenoliths is often twinned on (100).

Variation of the Amphiboles.

Attention has already been drawn in the preceding pages to the progressive recrystallization of the amphiboles in both the hornfelses and in the granodiorites. This recrystallization is accompanied by change in chemical composition, a fact which is indicated by the progressive variation in the optical properties of the minerals concerned.

The amphiboles of the hornfelses are mainly pale coloured, with Z showing in most cases a pronounced bluish pleochroic tinge, suggestive of appreciable soda content. The refractive index γ' taken on cleavage flakes varies from $1 \cdot 652$ to $1 \cdot 655$, a range which, when considered in conjunction with the pleochroism, places the mineral outside the normal tremolite-actinolite field. Rather it indicates a pargasitic species. The amphiboles of the xenoliths prolong this range with γ' varying from $1 \cdot 654$ to $1 \cdot 660$. The high value occurs in the banded hornblendic xenolith (Text-fig. 2A) in the porphyritic granodiorite. There is thus a progressive reconstitution from metamorphic amphibole to hornblende in the rocks of sedimentary parentage and their metamorphosed remnants in the granodiorites.

A similar progressive change can be traced in the amphiboles of the granodiorites. In the mixed marginal breccia the mineral has again pargasitic affinities, with $2V = 90°$ and $\gamma' = 1 \cdot 656 \pm \cdot 001$. In the microgranodiorite of Mt. Lednice $\gamma' = 1 \cdot 658$. In the non-porphyritic facies this value varies from $1 \cdot 658$ to $1 \cdot 659$. In the main pophryritic granodiorite, where the mineral is more robust and its inclusions are vanishing, γ' shows values $1 \cdot 659$ to $1 \cdot 663$.

These figures are diagrammatically summarized in Table II (p. 207).

Comparison of the changes of γ' shown in this table brings out the parallelism of the variation in the amphiboles which are contained in (I) the metamorphic, and in (II) the igneous host rocks. The progressive reconstitution of those minerals which are contained in the xenoliths, towards species similar to those of the main granodiorites is to be expected (Bowen, 1928, p. 198). On the other hand, the tracing backwards of the amphiboles of the igneous rocks shows that, whilst those of the porphyritic granodiorite are normal hornblendes, those of the other igneous types are more closely allied to metamorphic amphiboles; and their variation points to the progressive reconstitution of metamorphic amphiboles launched into the igneous mass as xenocrysts. This is supported by the evidence seen in the rocks at the margin of the batholith. The fact that these amphiboles form the main ferromagnesian constituent of the igneous rocks, and that they are ubiquitous throughout the suite indicates that the intrusion as a whole owes much of its character—either as the result of assimilation or by reaction—to the influence of the country rocks which it invades.

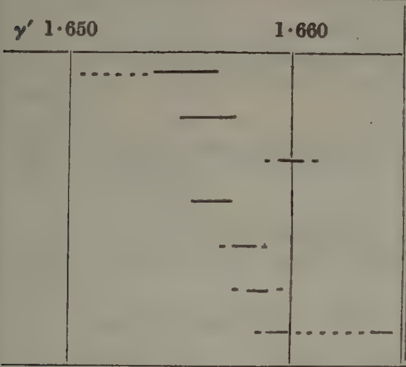
PETROGENESIS.

The Variation Diagram.

Analyses (Table III) of the various rocks described are plotted in a variation diagram (Text-fig. 5). The points fall into three groups: the first comprises two analyses of the brecciated margin (Nos. 150 and 149) and one (No. 221) of the monzonitic facies of the non-porphyritic granodiorite. The second contains the main granodioritic types, which show even spacing over a limited silica range of 62·59 per cent to 65·37 per cent. Their variation trend is normal. No. 187 is microgranodiorite; No. 311 is the non-porphyritic granodiorite; and No. 308 represents the porphyritic granodiorite. The other analysis of the non-porphyritic granodiorite (No. 227) was not plotted as its silica percentage is the same as that of No. 308; it was collected from a point just below the roof of the intrusion where its proximity to the sediments combined with possible upward migration of magmatic fluids have led to the concentration of silica and potash. Lastly comes the sodic aplite (No. 89) from Mt. Bedgerovac; this represents one of the large aplitic intrusions which lie to the east of the batholith.

TABLE II.

VARIATION OF γ' IN THE KOPAONIK AMPHIBOLES.



Host Rock-Types	
Marginal hornfels amphiboles.	I
Xenolithic types . .	
Banded hornblende xenolith.	
Marginal breccia amphiboles (2V = 90°).	II
Microgranodiorite (Mt. Lednice).	
Non-porphyritic granodiorite. . . .	
Porphyritic granodiorite.	

Except for the slight curvature of the lime curve, the variation throughout the suite is approximately straight line. The general slope of the curves, however, is that normally seen in rock-suites:

TABLE III.

ANALYSES OF THE GRANODIORITIC SUITE, KOPAONIK MOUNTAINS.

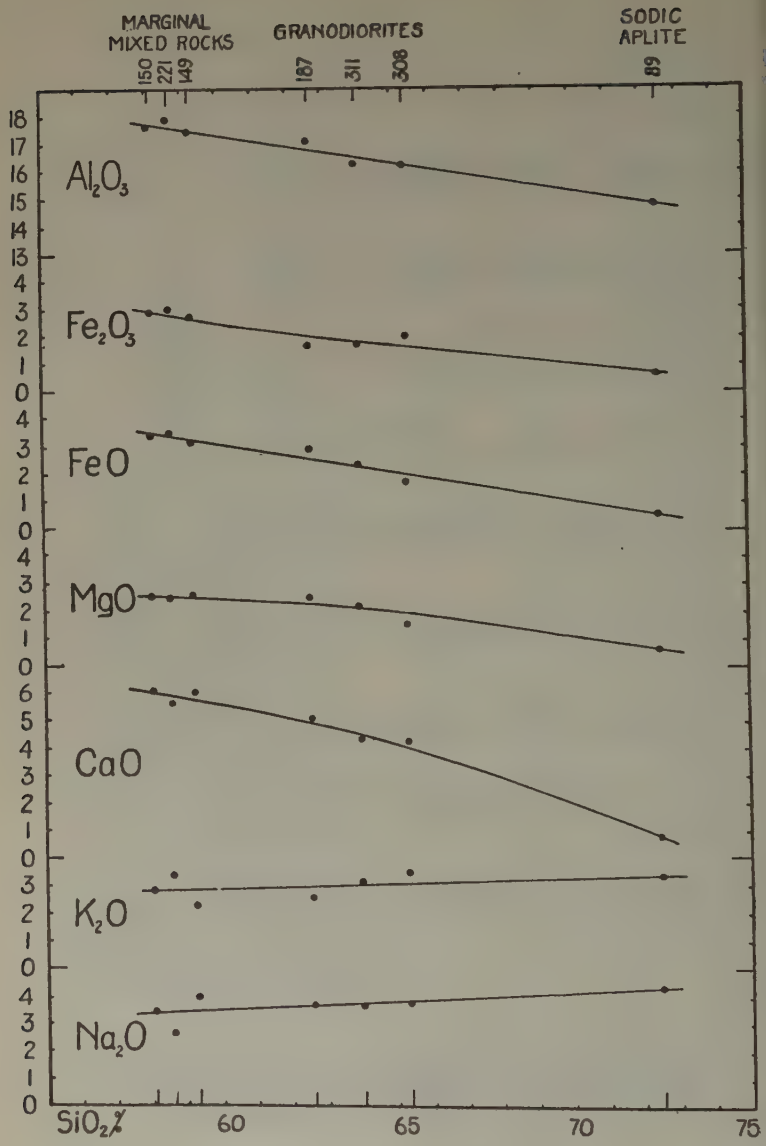
	Main Intrusive Types							Marginal Rocks		
No.	187	311	227	308	89	152	310	149	150	221
SiO_2	62·59	64·02	65·36	65·37	72·51	72·66	59·89	59·26	58·11	58·61
Al_2O_3	17·13	16·32	16·27	16·27	14·81	12·21	12·26	17·48	17·71	17·95
Fe_2O_3	1·72	1·71	0·86	2·06	0·63	0·14	4·22	2·74	2·88	2·97
FeO	2·98	2·40	1·73	1·87	0·55	2·34	5·27	3·19	3·41	3·51
MgO	2·49	2·17	2·09	1·52	0·61	0·96	4·06	2·58	2·51	2·84
CaO	5·10	4·34	4·72	4·14	0·77	2·54	5·65	6·05	6·10	5·58
Na_2O	3·77	3·70	3·43	3·78	4·32	2·65	2·72	4·00	3·47	2·66
K_2O	2·61	3·14	3·77	3·48	3·39	4·86	2·86	2·29	2·86	3·37
H_2O+	0·91	0·72	0·42	0·46	1·08	0·42	1·02	0·50	0·74	0·83
H_2O-	0·20	0·36	0·38	0·24	0·59	0·07	0·17	0·21	0·24	0·62
CO_2	none	none	none	none	none	0·40	none	0·15	0·12	tr.
TiO_2	0·69	0·63	0·65	0·53	0·18	0·14	1·35	0·60	0·61	0·49
P_2O_5	0·21	0·16	0·26	0·34	0·32	0·15	0·12	0·44	0·48	0·35
Cl	0·04	tr.	tr.	tr.	tr.	nd.	tr.	nd.	nd.	nd.
F	nd.	nd.	none	nd.	nd.	nd.	nd.	nd.	nd.	nd.
S	none	0·02	0·01	0·01	none	0·66	tr.	0·55	0·37	nd.
MnO	0·06	0·10	0·06	0·09	0·01	0·03	0·31	0·10	0·12	0·10
SrO	none	none	0·03	0·04	none	nd.	none	nd.	nd.	nd.
BaO	0·02	none	0·04	none	0·03	0·06	tr.	0·08	0·27	0·10
Li_2O	tr.	tr.	none	tr.	tr.	nd.	tr.	nd.	nd.	nd.
Less O	0·01					0·25		0·20	0·13	
Total	100·51	99·79	100·08	100·20	99·80	100·04	99·90	100·02	99·87	99·98

Norms.

Quartz	15·48	17·94	18·90	19·86	32·94	32·16	16·08	11·88	11·10	13·26
Orthoclase	15·57	18·35	22·24	20·57	20·02	28·91	17·24	13·34	17·24	20·02
Albite	31·96	31·44	28·82	31·96	36·15	22·53	23·06	34·06	29·34	23·06
Anorthite	21·96	18·63	18·07	17·24	1·95	6·95	12·79	23·07	24·19	25·02
Corundum	—	—	—	—	3·37	—	—	—	—	0·51
Diopside	2·03	1·77	2·65	1·09	—	1·86	11·65	2·77	2·10	—
Hypersthene	8·13	6·39	5·26	3·67	1·50	4·51	9·10	6·85	7·22	10·27
Magnetite	2·55	2·55	1·39	3·71	0·93	—	6·03	3·94	4·18	4·41
Ilmenite	1·37	1·22	1·22	1·06	0·46	—	2·58	1·22	1·22	0·91
Pyrite	—	—	—	—	—	1·20	—	1·02	0·72	—
Apatite	0·34	0·34	0·67	0·67	0·67	0·34	0·34	1·01	1·34	1·01
Calcite	—	—	—	—	—	0·90	—	0·30	0·20	—

No. 187 :	Microporphyritic granodiorite, from dyke on Saw Mill road.
No. 311 :	Non-porphyritic granodiorite, xenolithic raft in coarsely porphyritic type, 2,700 metres S.S.E. of the Saw Mill.
No. 227 :	Non-porphyritic granodiorite (monzonitic), from ridge between Mts. Suvo Rudište and Bedjerovac.
No. 308 :	Coarsely porphyritic granodiorite, from 400 metres north of Saw Mill.
No. 89 :	Sodic Aplite, from the north slopes of Mt. Bedjerovac.
No. 152 :	Potassic Aplite cutting marginal breccia, at the head of the Zaplanina river.
No. 310 :	Coarsely crystalline quartz-monzonite, from 1,600 metres south of the Saw Mill.
No. 149 :	Marginal breccia, from the head of the Zaplanina Creek, 15 cm. from the granodiorite-hornfels contact.
No. 150 :	Marginal breccia, same location, 1 metre from contact.
No. 221 :	Monzonitic facies, same location, 2 metres from contact.

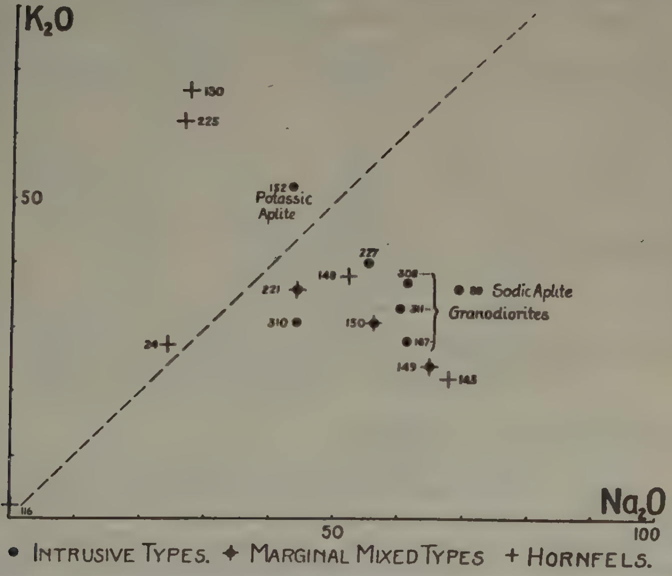
Analyses Nos. 187, 311, 227, 308, 89, and 310, by Dr. H. L. Riley, given in Wilson (1933).
Analyses Nos. 152, 149, 150, 221, by Dr. A. W. Groves.



TEXT-FIG. 5.—VARIATION DIAGRAM.

an increase in alkalies and diminution in other oxides with increasing silica content.

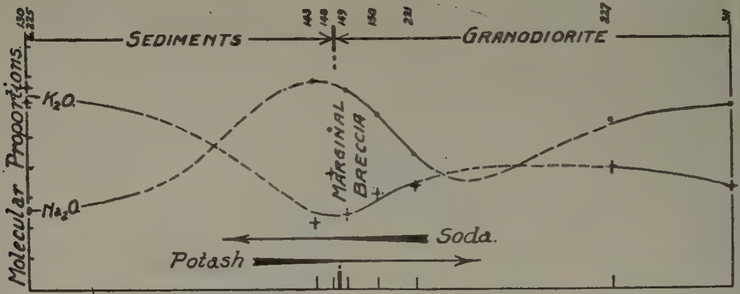
The dominance of soda over potash throughout the main igneous types is demonstrated in Text-fig. 6, where the molecular ratios of Na_2O and K_2O are plotted. The figure also shows the potassic nature of the hornfelses remote from the batholith margin, and the remarkable increase in soda-content of these rocks (Nos. 148 and 143) near and at the contact. This agrees with Brammall's and Harwood's conclusions (1932) concerning the migration of soda from acid magmas. The almost straight line variation shown here by the hornfelses from Nos. 130 to 143 suggests that potash emigration did not take place along with that of soda: the percentages of total alkalies in the rocks has remained practically constant; and in the hornfelses bordering on the granodiorite soda seems to have replaced potash as magmatic impregnation proceeded. The evicted potash from the sediments has tended to enrich the granodiorite locally in that constituent. The enrichment, however, is not at the actual margin of the granodiorite where incorporation of already soda-soaked material is still in progress, and where the percentage of soda is high (Anal. Nos. 150, 149); but lies further back in the



Text-fig. 6.—Plot of the Molecular Proportions of Potash relative to Soda.
No. 143: Na_2O, 4·18%; K_2O, 2·07%. Hornfels 15 cm. from the contact. Zaplanina river.
No. 148: Na_2O, 2·07%; K_2O, 3·64%. Hornfels at the contact. Zaplanina river. Anal.: A. W. Groves.

intrusion, as shown by the analyses of the monzonite No. 221 and the granodiorite No. 227. This potash enrichment has caused the local development of late orthoclase in the form of large poikilitic crystals, sometimes at the expense of plagioclase, and has imparted a monzonitic texture to the rock.

The two-way migration of alkalies at the batholith margin is diagrammatically illustrated in Text-fig. 7. The apparently anomalous position of the points for No. 148 is due to penetration of the specimen analysed by minor aplitic veining. Squeeze-out of late consolidating fluids from the zone of potash enrichment would result in the production of rock-types akin to the potassic aplite (Anal. No. 152) which cuts the marginal breccia in the bed of the Zaplanina river.



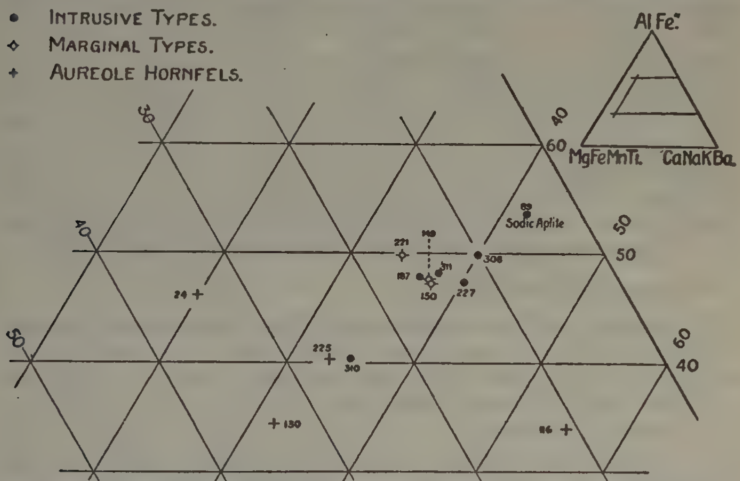
Text-fig. 7.—Showing diagrammatically the relative concentrations of alkalies at and near the batholith margin.

The Evolution of the Granodiorites.

In the case at present under consideration, the evolution of the granodiorites by differentiation from basaltic magma receives no support from either petrographical or chemical evidence. Not only does the most basic of the granodiorites closely resemble the marginal hybrids of the more acid non-porphyritic facies, but also it is richer in biotite than the most acid of the main intrusions, which is dominantly hornblendic. Further, such hornblende as does occur in the basic granodiorite is not in euhedral crystals, nor in reaction relation to augite, as would be expected in a type derived from direct precipitation. Instead it occurs as "anhedral wisps and aggregates". Finally the evidence of the formation and textural relationships of the ferromagnesian constituents of the suite as a whole is strongly opposed to the evolution of the rocks concerned by crystallization-differentiation. Hornblende usually encloses biotite poikilitically, and it can be observed to have developed, not by crystallization from magma, but by the recrystallization of porphyroblasts formed in xenoliths and sediments, and by reaction between the latter and the fluid phase of the intrusion in its marginal zones, with later progressive recrystallization of the original amphibole into robust hornblende.

The ubiquity of these crystals, which have a dominantly sedimentary parentage, throughout the granodiorites, suggests that either the batholith now represents the final product of granitization in place, or that an original magma, arising from an unknown depth, worked its way upwards by reaction with and assimilation of the sediments in its path. Of these two hypotheses that of granitization in place is not favoured. It may have occurred early in the history of the emplacement of the granodiorites, but proof is lacking. On the other hand, the chemical data and petrographical evidence both strongly support the idea of the evolution of the granodiorites from magma *plus* sediment.

Referring to the Variation Diagram (Text-fig. 5) it is noticeable that the points for the main granodiorites fall very closely to the straight lines joining those of the sodic aplite (No. 89) to the marginal mixed rocks. That is, any of the granodiorites might have been formed by mixture in suitable proportions of contaminated marginal material with magma akin to the sodic aplite in composition. As the hornfelses of the aureole have widely varying silica contents they cannot be plotted on the simple variation diagram. However, by plotting on an atomic basis (Text-fig. 8) after Brammall (1936) it is found that these altered sediments outline a well defined field differing markedly from that of the igneous rocks. The centre of this hornfels field lies approximately between points 130 and 225, whilst these two points themselves fall directly on the continuation of the line joining the sodic aplite (No. 89) to the main granodiorites and the marginal mixed rocks. Here again the relationship between these



TEXT-FIG. 8.—Plot showing the Atomic Proportions of the Main Intrusive Types, the Marginal Mixed Types, and their Relationships to the Aureole Hornfelses.

last and the more basic intrusives is clearly demonstrated; and the diagram as a whole indicates that chemically the granodiorites may be considered as mixtures, not only of marginal material and aplitic magma, but of hornfels and aplitic magma.

Another point of interest arising out of this figure is the position of point No. 310, which represents the composition of the gneissose quartz-monzonite bands occurring in the porphyritic granodiorite (see page 204). This rock is seen to have a composition more nearly related to that of the hornfelses than of the igneous rocks, though both its mineralogy and texture might suggest an igneous origin, save in respect to the hornblende-biotite association, which is characteristic of the xenocryst minerals of the plutonic suite. These dark, coarsely crystalline bands are, when compared with the normal granodiorites, rich in sphene, apatite, and myrmekite, all features which are indicative of hybridization (Nockolds, 1933; Hills, 1933; and Reynolds, 1934). Originally (Wilson, 1933) the origin of the rock was explained by crystal sinkage and late injection of accumulated material. This, however, does not explain its increased potash content relative to the normal types (Text-fig. 6), a feature which would be expected if the rock represents the last phases of metamorphism of a sedimentary roof-curtain that has undergone complete granitization *in situ* under the influence of magmatic soak. Its evolution would thus closely correspond with that of the gneisses of New Jersey described by Fenner (1914).

The Primary Magma Fluid.

The evidence for the evolution of the granodiorites from a mixture of recrystallized and assimilated sediment with a magma approximating in composition to that of the local sodic aplite (No. 89) has been outlined above. If this theory be sound the subtraction of the average composition of the hornfelses from the compositions of the granodiorites should yield a parent magma similar to the sodic aplite. The computation of a true average composition of the local hornfelses is, under the circumstances, virtually impossible, however an approximation to the average hornfels of the area has been made from the four analyses given in Table I. It is shown as 1 in Table IV. Subtraction of this average, by graphical construction, from the analyses of the microgranodiorite (No. 187), non-porphyritic granodiorite (No. 311), and porphyritic granodiorite (No. 308) yields a series of magma liquids which are peralkalic, dosodic, and peraluminous in composition (Table IV, A, B, and C). The average of these is given under D.

The chief differences between the calculated parent magma and the sodic aplite (E, Table IV) are greater richness in soda and alumina in the former. It has, however, been shown that soda is "sweated" out into the intruded sediments in advance of the magma (p. 211). Probably alumina accompanied the soda, as it is now well established that the alkali-aluminous constituents of magma are highly mobile in some form or other, and may cause pre-intrusion permeation of the country rock (Backlund, 1936; Reynolds, 1937; Holmes, 1937; and MacGregor, 1937). Hence it appears that the reaction between the invading material—*magma* in its widest sense—and the pre-existing country rock took place in two overlapping stages: an alkali(sodic)-aluminous metasomatism, followed by the incorporation of the metasomatized material by an advancing siliceous melt. The composition of this latter would therefore be poorer in soda and alumina than that of the computed parent magma, and so would closely approximate to that of the sodic aplites found in the field. These would thus be the late, relatively cold representatives of the original parent magma, which having lost its volatile constituents, crystallized as a fine-grained rock, and was unable to assimilate or react with the wall-rocks.

TABLE IV (i).

COMPUTED COMPOSITIONS OF INITIAL KOPAONIK MAGMA.

	1.	A.	B.	C.	D.	E.
SiO_2 .	54·0	71·7	72·8	72·2	72·2	72·51
Al_2O_3 .	15·5	19·0	17·5	17·1	17·9	14·81
Fe_2O_3 .	3·2	0·4	0·9	1·6	1·0	0·63
FeO .	5·9	0·6	0·2	0·1	0·3	0·55
MgO .	5·0	0·4	0·4	*nil*	0·3	0·61
CaO .	11·3	*nil*	*nil*	1·0	0·3	0·77
Na_2O .	1·2	6·1	5·5	5·0	5·5	4·32
K_2O .	3·9	1·7	2·7	3·3	2·5	3·39
						+ 2·21
Total .	100·0	99·9	100·0	100·1	100·0	99·80

1. Average Kopaonik hornfels computed from Table I.
A. Computed magma to yield microgranodiorite No. 187.
B. Computed magma to yield non-porphyritic granodiorite No. 311.
C. Computed magma to yield porphyritic granodiorite No. 308.
D. Average of A, B, and C.
E. Sodic aplite, analysis No. 89, from Table III.

(ii).

PERCENTAGE RATIO OF AVERAGE HORNFELS TO COMPUTED MAGMA TO FORM THE MAIN ROCK-TYPES.

		Hornfels. *per cent.*	*Magma.* *per cent.*
No. 187.	Microgranodiorite . .	44	56
No. 311.	Non-porphyritic granodiorite .	39	61
No. 308.	Porphyritic granodiorite .	30·5	69·5

From the composition of the initial magma which is considered to have given rise to the granodiorites, it is possible to estimate the relative proportions, fluid to sediment, of the mixtures which yielded the main rock-types (Table IV (ii)).

Thus progressive acidity and evolution towards granite is, in this case, essentially a function of the ratio of primary magma to material assimilated. Similar phenomena have been noted at Shap (Grantham, 1928; and Brammall, 1933, p. 105).

The possible origin of this parent magma is suggested by its (normative) quartz-feldspar ratio, which lies relatively close to the eutectic proportions as estimated by Vogt :—

Computed initial magma to form :—

		Quartz. *per cent.*	*Feldspar.* *per cent.*
No. 187.	Microgranodiorite . . .	32·5	67·5
No. 311.	Non-porphyritic granodiorite .	32·5	67·5
No. 308.	Porphyritic granodiorite .	29·6	70·4
	Average . . .	31·5	68·5
Vogt's eutectics		26–28	74–72.

Further, the plotting of the average initial magma composition on Bowen's (1937, figs. 7 and 8) equilibrium diagram of the system $NaAlSiO_4$—$KAlSiO_4$—SiO_2 gives a point which lies just beside the left edge of his low temperature field, and between the margin of the tridymite field and the 1050° isotherm.

Such material would be the last to solidify from a differentiating mass of initially more basic parentage, or contrariwise, the first to fuse in the case of differential anatexis (Eskola, 1933). Were the Kopaonik intrusions of Archaean age, then their evolution from a derivative of (?) basaltic parentage would merit serious consideration. On the other hand, it is now reasonably certain that many of the later acid intrusions in orogenic belts are derived, in part at least, by fusion or partial fusion of the sialic roots of their fold systems (Eskola, 1932 ; Brammall, 1933 and 1932 ; Daly, 1933 ; and others). The mechanisms whereby the necessary heat for this refusion could be supplied from the underlying basaltic or peridotite layers has been discussed by many writers, and it is generally acknowledged that such supply is adequate.

The sodic to sodi-potassic nature of the Kopaonik granodiorites and associated rocks would be the natural result of such anatexis in an area where early (pre-orogeny) greenstones are known to occur. These latter in all probability must have caused local, or possibly even widespread, albitization of the substrata. A phenomenon which would automatically tend to be reflected in the composition of later products derived therefrom.

Summary and Conclusions.

The composite granodiorite batholith of the Kopaonik Mountains forms one of the more southerly members of the peri-Adriatic tonalitic intrusions. In the area discussed in this paper it intrudes a series of sedimentary rocks which range from dominantly calcareous to pelitic types. Metamorphism of these rocks has produced crystalline limestones, skarns, and calc-silicate hornfelses, which grade downwards into mica-, amphibole-, epidote-, and locally cordierite-bearing rocks. The pelitic and amphibole-bearing hornfelses are in immediate proximity to the batholith on the surface. The amphibole-bearing types are mainly confined to a relatively small area, well within the zone of high-grade metamorphism and overlying the southerly pitching nose of the intrusion. With them are associated hornfelses which carry porphyroblasts of albitic feldspar. It appears that the persistence of the amphibole and the development of these feldspar porphyroblasts may have been caused by hydrous and probably sodic emanations which permeated the sediments above and ahead of the advancing igneous mass.

Where the contact between the igneous rocks and the hornfelses is to be observed, the former are considerably modified by assimilation of the latter. Amphibole derived directly from the sediments as well as by reaction between magmatic fluid and sedimentary material at the igneous contact is recognizable throughout the marginal zone. Such amphibole has a characteristic spongy texture and carries included flakes of biotite and small crystals of other minerals. Being in equilibrium with the fluid igneous material of the intrusion, this amphibole persists, recrystallizes, and grows—largely at the expense of its inclusions—into green hornblende, which is the dominant ferromagnesian mineral of the main granodiorites. Biotite xenocrysts, launched into the igneous mass at the same time as the amphibole, are made over to amphibole if small, but if large they tend to persist. This addition of xenocrystic material to the intrusion causes an apparent reversal of Bowen's reaction series: the more basic granodiorites are biotite-amphibole types, and the more acid are dominantly hornblendic. The widespread occurrence, throughout the intrusive suite, of hornblendes of which the origin is known to be intimately connected with the local hornfelses, indicates that very considerable modification of the original intrusive magma has been brought about by incorporation of sedimentary matter. Where observed, this contamination process has been mainly one of reaction between igneous magma fluid and sedimentary matter, followed by piecemeal stoping and recrystallization of the incorporated material. Hence the granodiorites of the area are considered to be of mixed origin, and largely owe their petrographical character to the rocks they invade.

Study of the bulk analyses of the various members of the suite confirms this petrographical conclusion, and shows that the main intrusive types have compositions indicative of mixture of hornfelsic material and an acid parent magma. The composition of this acid magma has been computed and, allowing for losses due to early permeation of the country rocks by Na- and Al-bearing emanations, it closely approximates to that of the large aplitic intrusions which break through the sediments to the east of the batholith. Variations in composition of the different granodiorites can thus be explained as being functions of the relative proportions of initial magma to incorporated sedimentary material.

ACKNOWLEDGMENTS.

The writer wishes to thank the Directors of Kopaonik Mines, Ltd., for permission to publish this paper based on material collected whilst he was in their employment. The earlier laboratory work was undertaken in the Geological Department of the Imperial College of Science and Technology, London, and was continued at the University of Reading, and at University College, London. For many helpful suggestions the writer is most grateful to Dr. Malcolm MacGregor; and to Professor A. Brammall he is indebted for continual encouragement and constructive criticism, both in the field and the laboratory.

A representative suite of specimens from this area is housed in the Department of Petrology at the Imperial College of Science and Technology, London, S.W. 7.

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The Contact Zone of Sheep Creek, Little Belt Mountains, Montana.

By J. H. TAYLOR.

INTRODUCTION.

DURING the recent construction of a new highway linking Glacier and Yellowstone National Parks a number of deep cuttings have had to be made in the Little Belt Mountains. Some nine miles south-south-east of the once prosperous mining town of Neihart the road crosses the divide at King's Hill (7,400 feet O.D.) and, passing from Cascade County into Meagher County, starts a long and gradual descent into Sheep Creek. Along the side of the creek for a distance of several miles a series of sections reveal that the country rock is here cut by igneous intrusions with interesting contact-metamorphic effects. The mineralogy of the contact rocks has already been described by the author (1)[1]: the present communication describes the field relations and considers some problems of paragenesis.

FIELD RELATIONS.

The country rocks consist of a series of shales and limestones belonging to the Middle Cambrian Barker Formation and having a gentle dip to the south. Owing to the forested nature of the ground, exposures are almost confined to the road cuttings along the side of the valley and to the bed of Sheep Creek below. As far as can be gathered from these the greater part of the formation is shale, but at two points at least in the succession there are intercalations of limestone. One of these is over 50 feet thick, the other somewhat less: in the main these bands consist of pure limestone, but near the top and bottom there is considerable interbedding with thin layers of shale.

Into these sediments a series of lamprophyric rocks have been intruded, possibly as a number of distinct bodies but obviously genetically connected. In form these bodies are frequently sill-like, but a vertical cross-cutting relationship is also seen. Text-fig. 1 shows the contact of one of the intrusions concordant with the bedding of the shaly limestones underneath; while Text-fig. 2, taken from another section, illustrates a discordant junction. In Text-fig. 3 a contact with the shales is depicted. At the north end of the section the bedding of the thin (3–4 feet) bands of shale is completely undisturbed: while at the south end the magma, apparently unable to find its way further along the bedding planes, has given rise to intense contortion and puckering of the shales. The maximum thickness exposed in any one sill is less than 50 feet but, judging from the cross-cutting relationship of the igneous rock in Text-fig. 2, it seems probable that the sheets are connected. The vertical range of the intrusions is considerable, as indicated by the occurrence of similar rocks in the bed of Sheep Creek about 1,000 feet below the highest exposure along the roadside.

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[1] Numbers in parentheses refer to References at end of article.

Fig. 1.

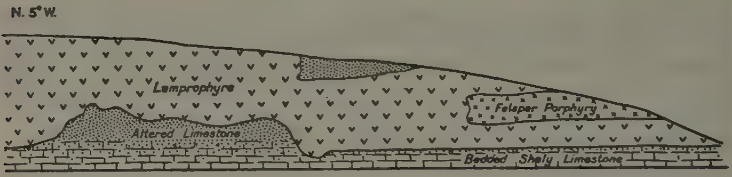


Fig. 2.

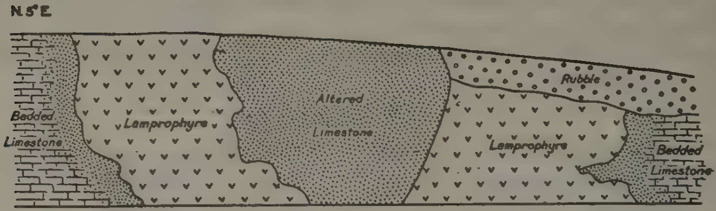
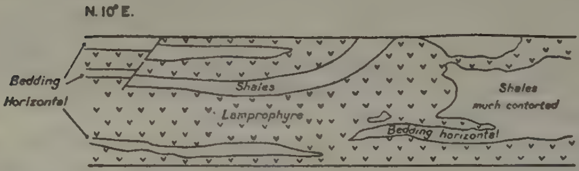


Fig. 3.



Sketch sections of Contact between Lamprophyre and Sediments.
Scale: 1 in. = 30 ft. (vertical and horizontal).

The Altered Limestone.

The contact-metamorphosed limestone consists of the usual sharply contrasted light and dark facies. The former is by far the more abundant and passes outwards from the contact into unaltered limestone. This passage is sometimes gradual from lime-silicate rock ⟶ marble ⟶ limestone, but is often surprisingly sharp, less than a couple of inches separating altered and unaltered limestone. The extent of the zone is extremely variable: in some cases it may be 50 feet or more thick, in others, as at the lower contact of the igneous rock in Text-fig. 1, unaltered limestone occurs only a few inches from the junction.

The dark coloured facies, the "tactite" of Hess (2), is much more limited in extent and is, in general, localized near the contact. In some cases there is an irregular band of the dark material, seldom more than 6–8 inches wide, separating the zone of light silicates from the igneous rock, but this is by no means invariably present. Beyond this zone patches of the dark material appear within the light and decrease in number and size away from the contact. A small inclusion of altered limestone within the igneous rock showed beautifully the relation between the tactite zone and the calc-silicate rock, a core of the latter 1½–2 in. across being separated from the lamprophyre by a ring ½ in. thick of dark hornfels. Frequently, however, inclusions of light silicate material are found in the lamprophyre without any sign of the tactite.

Everywhere the junction between the light and dark silicate zones is remarkably sharp and there is little trace of gradation from one rock to the other. In this, as in many other respects, the Sheep Creek rocks closely resemble the tungsten contact-metamorphic deposits described by Hess and Larsen (3). In the same way the junction between the igneous rock and the tactite is generally sharp; though much less obvious owing to the similarity in colour of the two rocks. There is no evidence of any assimilation at the contact or modification of the magma by incorporation of limestone.

Discussion of the Metamorphic Effects.

(1) *The Igneous Rock.*—The igneous rock was referred to by Weed and Pirsson (4) as a minette, though under Johannsen's classification it falls in the melagabbro group. Neither of these names appear suitable, however, since the former implies that orthoclase is the dominant felspar, while the latter completely fails to suggest the biotite-rich nature of the rock. For the sake of simplicity the general term lamprophyre is retained. Over a great part of its outcrop the igneous rock is very rotten. Spheroidal weathering is well developed and only from the centre of the spheroids can material fresh enough for microscopic examination be obtained.

The dominant constituents are pyroxene, biotite, and labradorite, with or without hornblende and orthoclase, and with pseudomorphs of serpentine and talc after olivine. The pyroxene is a colourless augite frequently disposed in reaction relation round the margin of the olivine pseudomorphs. The latter have the unmistakable form of olivine prisms capped by steep bipyramids, but it is rarely that any of the original mineral is left in the centre of the replacing talc and serpentine. Biotite is plentiful in fibrous laths with pleochroism pale straw yellow—olive brown and frequently a dark border suggesting reaction either with the residual magma or with hydrothermal solutions. Hornblende, which is never abundant, is a green variety with $c \wedge Z = 23°$ and pleochroism

X = pale straw yellow.
Y = dark greenish brown.
Z = green.

The dominant felspar is a rather cloudy plagioclase with a composition—as determined by measurement of the indices—of Ab_{35} An_{65}, and may be accompanied by varying amounts of orthoclase. The analysis (I, p. 225) is not greatly different from that of an augite-minette from the head of Sheep Creek (I*a*.) recorded by Weed and Pirsson, but is somewhat richer in silica and magnesia and poorer in ferric oxide and lime.

At the actual contact with the tactite the rock has undergone a marked change. Plagioclase has given place to orthoclase, biotite has decreased in amount and olivine completely disappeared. In some specimens pyroxene is present, in others it has apparently broken down to an aggregate of antigorite, uralite and chlorite. Consideration of the analysis (II) of a specimen of altered lamprophyre immediately within the contact shows that these mineralogical changes are accompanied by changes in chemical composition. As compared with the unaltered lamprophyre the marginal rock has gained alumina, ferric iron, potash and lime, while it has lost silica, magnesia, ferrous oxide and soda. These changes can hardly be the result of reciprocal reaction between igneous rock and sediment, for analyses of the altered limestone (p. 225) show that it also has been enriched in alumina and ferric iron. Nor can there have been any great assimilation of limestone at the contact, for recalculation of the analyses of altered and unaltered lamprophyre, omitting water and carbon dioxide, shows a gain of only 1·5 per cent of lime in the marginal rock.

Thus both the chemical and the microscopic evidence bear out the field evidence that there is nothing in the nature of a hybrid zone present. The plagioclase (labradorite) of the normal lamprophyre instead of being rendered more calcic has given place to orthoclase. It appears most probable that this, together with the changes in the coloured minerals, is the result of reworking by hydrothermal solutions of late magmatic origin which found their way along the junction of the igneous rock and the limestone.

Locally associated with the lamprophyre are some small bodies of felspar-porphyry consisting of phenocrysts of oligoclase and a little biotite set in a fine-grained groundmass of quartz and orthoclase. These rocks, which are of a type commonly occurring in composite intrusions with the lamprophyres, do not appear to have had any direct connection with the metamorphic phenomena.

(2) *The Shale.*—The unaltered shale (Analysis V) is a fine-grained dark-coloured rock consisting of an aggregate of micaceous

and chloritic flakes with smaller amounts of quartz and iron ore. Near the contact with the lamprophyre the rock is perhaps a little darker and more compact and has often had a fine slaty cleavage imparted to it. Spotting is not evident in the hand specimen but is conspicuous under the microscope where, in certain cases, brown spots and blotches are seen to comprise more than 50 per cent of the rock. With increasing metamorphism white mica appears in new flakes, much larger than the original minute scales, and cordierite is abundantly developed; occasionally a few laths of brown biotite are present.

These feeble metamorphic effects are in marked contrast to those produced on the limestone. In one exposure where a band of limestone 1½ ft. thick is interbedded with shales a thin tongue of lamprophyre has found its way between limestone and shale. The limestone has been converted into a garnet-vesuvianite rock while the shale shows only faint spotting. This and other field evidence of the same nature points to the much greater susceptibility of the limestone than the shale to metamorphism by the lamprophyre.

(3) *The Limestone.*—Specimens of the limestone remote from the contact show the rock to be moderately pure. It consists of a fine-grained aggregate of calcite with numerous rounded and elongated structures which are probably oolitic rather than organic in origin. The only impurities are some large grains of quartz and a little pale green interstitial serpentinous material: dolomite appears to be quite absent. The analysis of this rock (VI) shows 48·69 per cent of lime and only 1·12 per cent of magnesia, the latter probably accounted for by the serpentinous material. Other impurities include 8·90 per cent silica, 2·24 per cent alumina, and 1·39 per cent combined iron oxides.

Metamorphism of the limestone has given rise to a series of hornfelses that may be listed as follows:—

Zone of Dark Silicates	(1)	Diopside-garnet-calcite rock.
	(2)	Diopside-wollastonite-calcite rock.
	(3)	Diopside-forsterite-wollastonite rock.
	(4)	Diopside-calcite-chrysolite rock.
	(5)	Diopside-plagioclase rock.
	(6)	Diopside-plagioclase-biotite rock.
	(7)	Diopside-orthoclase-biotite-calcite rock.
	(8)	Diopside-orthoclase-forsterite rock.
	(9)	Gehlenite-merwinite rock.
Zone of Light Silicates	(10)	Calcite-vesuvianite-gehlenite-scawtite rock.
	(11)	Vesuvianite-antigorite-calcite rock.
	(12)	Garnet-vesuvianite-wollastonite-calcite rock.
	(13)	Garnet-vesuvianite-calcite rock.
	(14)	Calcite-garnet rock.

Despite the variety of these rock types it will be seen that the great majority of them are related to Goldschmidt's Classes 7, 9, and 10. In the dark silicate zone, the most abundant minerals are diopside, orthoclase, garnet,[1] and wollastonite; in the light silicate zone, garnet and vesuvianite. Free quartz is commonly present. With the exception of the gehlenite-merwinite and calcite-vesuvianite-gehlenite-scawtite rocks, which are rare types, all the hornfelses may contain greater or less amounts of prehnite, and of sulphides of iron, copper, and zinc. In the dark silicate zone prehnite is sometimes so abundant as to be the dominant constituent: in the light silicate zone it is much rarer. Similarly the sulphides pyrite, chalcopyrite, pyrrhotite and sphalerite are widely spread through the tactite but less common in the light zone.

On page 225 are given analyses of (III) a diopside-orthoclase-forsterite-(biotite) hornfels from the dark silicate zone and (IV) a garnet-vesuvianite-calcite rock from the light zone. Of the two, the former is noticeably richer in silica, alumina, ferrous iron, magnesia, potash, and soda. It will be seen that while the analysis of the tactite falls into a normal rang and sub-rang, the light silicate hornfels has chemically nothing in common with any igneous rock.

Comparison of these analyses with that of the unaltered limestone (VI) shows that both light and dark silicate zones are richer in silica, alumina, iron and magnesia, while the tactite is in addition enriched in soda and potash. Three possible sources for these constituents are evident:—

(1) Consideration of the analysis of the shale (V) suggests that shaly material locally interbedded with the limestone might well provide the necessary silica, alumina, iron, soda, and potash, but it appears inadequate to account for the magnesia. Nor does the field evidence suggest that metamorphism has affected limestone and shale together. On the contrary, where interbedding does occur the metamorphism has followed the limestone bands, leaving the shale practically untouched. Text-fig. 1 shows unmetamorphosed shaly limestones at the lower contact of one of the lamprophyre sheets. If the metamorphism were purely thermal it is difficult to see why the sediments should be unaffected just where their composition was particularly suitable for the formation of lime silicate rock.

(2) Removal of calcium carbonate in solution from the limestone might in time provide a concentration of the other oxides similar to that shown by the analyses of the metamorphic rocks. For example, if all the normative calcite is subtracted from the limestone and the analysis recalculated, the result (VI (*a*), p. 225) is by no means dissimilar to the analysis of the tactite, although, once again, there is a deficiency of magnesia. Similarly, subtraction of some seven-eighths of the normative calcite and recalculation gives an analysis (VI (*b*)) agreeing reasonably with that of the

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[1] The garnet is a lime-iron variety with optical properties approaching most nearly to those of hessonite.

ANALYSES.

	I	I (*a*)	II	III	IV	V	VI	VI (*a*)	VI (*b*)
SiO_2 .	55·24	52·26	50·13	42·40	25·02	52·39	8·90	44·9	29·8
Al_2O_3 .	14·13	13·96	17·92	10·78	8·98	24·23	2·24	11·3	7·5
FeO .	4·23	4·45	1·32	4·14	0·44	4·13	1·22	6·2	4·1
Fe_2O_3 .	1·85	2·76	2·95	2·43	6·76	3·52	0·17	0·9	0·6
MgO .	7·38	8·21	2·34	9·81	2·74	2·14	1·12	5·7	3·7
CaO .	5·72	7·06	6·66	16·22	38·05	0·87	48·69	19·2	31·6
Na_2O .	2·91	2·80	2·02	1·34	Trace	0·71	Trace	Trace	Trace
K_2O .	3·41	3·87	4·68	1·59	0·21	4·94	0·21	1·1	0·7
MnO .	0·09	0·14	0·07	0·13	0·68	—	0·15	0·8	0·5
TiO_2 .	0·53	0·58	0·59	0·59	0·24	0·58	Trace	Trace	Trace
H_2O- .	1·60	1·53	4·20	1·40	0·60	1·70	0·30	10·0	6·6
H_2O+ .	1·62	1·34	3·85	6·15	2·05	4·45	1·68		
CO_2 .	0·78	0·49	2·90	2·80	13·40	—	35·23	—	14·8
P_2O_5 .	0·39	0·52	0·26	0·29	0·87	0·09	Trace	Trace	Trace

I. Unaltered lamprophyre, Sheep Creek. Analyst: W. H. Herdsman.

I (*a*). Minette, head of Sheep Creek. Analyst: W. F. Hillebrand. In *20th Ann. Rep. U.S.G.S.*, pt. 3, p. 531.

II. Altered lamprophyre, Sheep Creek. Analyst: W. H. Herdsman.

III. Altered limestone, dark silicate zone, Sheep Creek. Analyst: W. H. Herdsman.

IV. Altered limestone, light silicate zone, Sheep Creek. Analyst: W. H. Herdsman.

V. Unaltered shale, Sheep Creek. Analyst: W. H. Herdsman.

VI. Unaltered limestone, Sheep Creek. Analyst: W. H. Herdsman.

VI (*a*). Recalculated analysis of unaltered limestone after removal of normative calcite.

VI (*b*). Recalculated analysis of unaltered limestone after removal of seven-eighths of normative calcite.

NORMS.

		Unaltered lamprophyre (shoshonose).	*Altered lamprophyre (adamellose).*	*Altered limestone of dark silicate zone (auvergnose).*
Quartz . . .		4·02	11·28	—
Orthoclase . . .		20·02	27·80	9·45
Albite . . .		24·63	17·29	8·91
Anorthite . . .		15·57	12·79	18·63
Plagioclase composition		$Ab_{46}\ An_{54}$	$Ab_{42}\ An_{58}$	$Ab_{20}\ An_{80}$
Nepheline . . .		—	—	1·42
Diopside	$CaSiO_3$	2·09	—	17·63
	$MgSiO_3$	1·50	—	13·20
	$FeSiO_3$	0·40	—	2·64
Hypersthene	$MgSiO_3$	17·00	5·80	—
	$FeSiO_3$	5·02	—	—
Olivine	Mg_2SiO_4	—	—	7·98
	Fe_2SiO_4	—	—	1·63
Magnetite . . .		2·78	2·78	3·51
Ilmenite . . .		1·06	1·06	1·06
Haematite . . .		—	0·96	—
Corundum . . .		—	4·79	—
Apatite . . .		1·01	0·67	0·67
Calcite . . .		1·80	6·60	6·40

altered limestone from the light silicate zone, for all constituents except iron oxides. Such changes, however, require an enormous decrease in volume of the limestone and, despite a certain amount of crushing and shearing, there does not appear to be adequate field evidence of this.

(3) Finally, it is possible that fresh constituents may have been directly introduced into the limestone by hydrothermal solutions. The principle of introduction of material during contact metamorphism is widely recognized in America, but is somewhat out of favour with British petrologists. Harker (5), in discussing the matter, points out that, though residual magmatic liquids may contain silica, iron, soda, and water, they must normally be devoid of magnesia, which has been extracted from the magma in the earlier stages of crystallization to form olivine, pyroxene, amphibole, or biotite. At Sheep Creek, however, it appears that the 9·8 per cent of magnesia in the tactite is too much to be accounted for by original material in the country rock, and one is forced to the conclusion that by some means or other it has been introduced.

Which of these three processes was chiefly responsible for the composition of the metamorphic rocks is a question on which the writer is not prepared to commit himself. While there is no reason to doubt that part of the silica, alumina, iron, and magnesia were originally present in the country rock, it appears probable that there has been some material introduced by hydrothermal solutions.

In conclusion the author wishes to acknowledge his indebtedness to Dr. J. Phemister for helpful advice and criticism, and to the Dixon Fund of London University for a grant defraying in part the cost of chemical analyses.

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Stratigraphical Correlation by Small Foraminifera in Palestine and Adjoining Countries.

By F. R. S. Henson.

I. Introduction.

THE purpose of the present note is to give a synopsis of the most important differences between assemblages of small foraminifera from rocks of Upper Cretaceous, Eogene, and Neogene age respectively, in the Middle Eastern region.

As a result of work on many thousands of samples it has been found that certain conspicuous features of successive microfaunas are sufficiently characteristic to serve as evidence for approximate age determinations of foraminiferal chalks, marls, or shales which are often difficult to correlate by other means especially when they are found in small, isolated outcrops or in borings.

Recognition of these features is well within reach of field geologists who are prepared to carry with them portable equipment of the type designed by the author (10)[1] and to spend some time with the microscope. Many problems may be settled beyond question by this method, but no attempt should be made to stretch the results too far when dealing with assemblages of foraminifera that cannot be placed with certainty in one or other of the broad groups defined below.

The successive microfaunas grade into each other in a continuous sequence and sometimes alternate in the transitional zones so that more accurate correlation of horizons, where possible at all, depends upon a careful study of the local ranges of a large number of species. Such details are, however, beyond the scope of this note, in which attention is concentrated on the dominant characters of the microfaunas and on a few of the most useful and easily identified foraminifera of limited time range in the given region.

The distribution of individual species shown on page 229 may be subject to minor modifications if and when more exact control is obtained by means of other fossils of proved stratigraphical value; but in all essentials the picture presented is well established by field and fossil evidence, much of which is given in the references quoted below.

For descriptions of the genera and species mentioned the reader is referred to the literature.

Modern textbooks on the foraminifera deal adequately with the technique of micropalaeontology (5, 9), but special stress may be laid firstly on the value of acid digests (HCl) in isolating siliceous organisms, gypseous casts, etc., and secondly on the desirability of examining all rocks in thin sections. This last method frequently shows the general composition of a microfauna and may establish the presence of genera of determinative value.

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[1] Numerals in parentheses refer to the list of literature on page 233.

II. CHARACTERISTIC MICROFAUNAS.

References are given to sections where the features described may be studied in rocks of suitable facies.

Upper Cretaceous.

Palestine.—Santonian-Campanian-Maestrichtian-Danian (part) of Picard (12; pp. 9–61); Senonian of Avnimelech (2; pp. 40–62); Group G–J of Henson in Blake[1] (3; pp. 32, 33, 43–50).

Syria.—" Craie blanche Maestrichtienne " (lower half) of Soukhne Section (7; p. 78).

Iraq Basin.—" Green and Purple Globigerina Marls " (lower part), " Cream-coloured Calcareous Marls " and " Blue and black Globigerina Marls with *Lopha dichotoma* Bayle ", of Imam Hassan Section (4; p. 89).

Egypt.—Suez–Mitla Road, 40 km. east of Suez, Upper Cretaceous Chalks (C 3) (1).

Upper Cretaceous marls, chalks, and shales are readily distinguished from lithologically similar material of Tertiary age by the presence of species and genera that do not survive the Cretaceous in the region concerned; among these the most distinctive are *Globotruncana* [*Rosalina*], large and ornamented species of *Gümbelina*, *Pseudotextularia*, *Bolivinoides*, *Bolivina incrassata* Reuss, *Gaudryina rugosa* (d'Orb.).

Species which extend into the Tertiary, but are particularly abundant and characteristic in the Cretaceous include *Anomalina ammonoides* (Reuss) and *Globigerina cretacea* d'Orb. and its near allies. Globigerininae other than these compressed forms are, as a rule, relatively rare and poorly developed in the Upper Cretaceous of Palestine and surrounding regions; *Globorotalia*, except *G. stuarti* (de Lapparent), is common only in the highest horizons (see below). Species of *Gümbelina* and *Globotruncana* are frequently mistaken for *Globigerina* and *Globorotalia* in thin sections, while *Gümbelina* is recorded as *Textularia* by many authors.

Cretaceous-Eocene Contact: Transitional Microfauna.

Palestine.—Sar'a Beds (lower part) of Avnimelech (2; pp. 67–79); " Lower Chalky Layers " of Picard (13; p. 188); Group F of Henson in Blake (3; pp. 28–43).

Egypt.—Danian of Gebel Gournah (Qurna) (6; p. 58); Palaeocene and L. Eocene of Farafra Oasis (6; p. 52).

Iraq Basin.—" Green and Purple Marls " (upper part) of Imam Hassan Section (4; p. 95).

In areas where sediments with small foraminifera extend from the Cretaceous into the Eocene, a clear division can be made between

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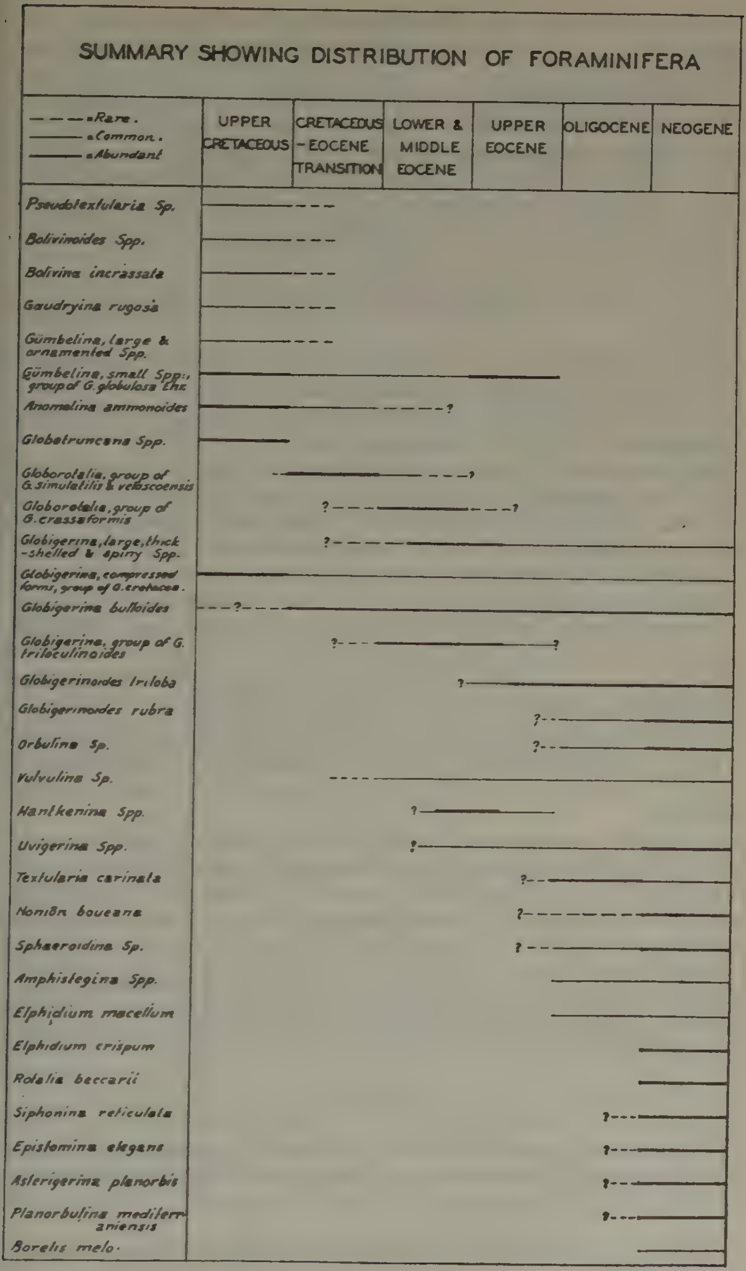
[1] In the publication cited some confusion arises owing to independent use of a similar stratigraphical symbolism by the present author and other observers; certain misleading statements also occur.



SUMMARY SHOWING DISTRIBUTION OF FORAMINIFERA a lower section with a *Globotruncana-Gümbelina* fauna as described above and an upper section with predominant *Globigerina* and *Globorotalia.*[1]

If there are indications in the sequence of unconformity or "stratigraphic condensation", the division is usually sharp and occurs at the horizon of the break where the faunas may be mixed by re-working; but where sedimentation was continuous there is often a transition zone characterized by an abundance of sharply-keeled *Globorotalias* of the group of *Globorotalia simulatilis* (Schwager) and *Globorotalia velascoensis* Cushman, associated with predominant Globigerininae (*G. bulloides* d'Orb., etc.), which are much more numerous, varied, and robust than those of normal Upper Cretaceous assemblages.

This distinctive transitional microfauna extends from the highest Danian, where it contains rare survivors of typical Upper Cretaceous species, into early Eocene where the first Tertiary genera (*Vulvulina*, *Nummulites*, *Discocyclina*, etc.) may appear.

Species of the *G. simulatilis-G. velascoensis* group persist with greatly diminishing frequency at least up to the Ypresian.

Since the *Globigerina-Globorotalia* fauna first appears in the uppermost Danian, the exact Cretaceous/Eocene contact can be located in a continuous sequence only by careful analysis of the foraminiferal assemblages and even then there may be some uncertainty owing to slight overlap of Cretaceous and Tertiary species.

As a general rule, however, the junction between the *Globotruncana-Gümbelina* and the *Globigerina-Globorotalia* microfaunas may be accepted, where other evidence fails, as a reasonable approximation to the Cretaceous/Eocene contact, though this interpretation conflicts with some of the lithological mapping of the region already published.

In certain sections the "transitional fauna" is not typically developed at the contact of the Cretaceous and the Eocene even where there is no lithological evidence of a break in deposition. Careful study is required in such cases to decide whether an imperceptible gap occurs or whether the *simulatilis-velascoensis* group is absent owing to other causes. The first alternative is most likely to be correct since the group has been found in rocks of varying facies (clays, marls, shales, limestones, cherts) at widely separated localities in the Middle East.

Eocene.

It is not always possible to distinguish subdivisions of the Eocene, but in sections where the microfaunas are well differentiated the following may be recognized.

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[1] Compare observations by D. Schneegans in the Flysch of Ubaye-Embrunais (15).

Lower and Middle Eocene.

Palestine.—Sar'a Beds (upper part) of Avnimelech (2; pp. 67–79); "Flinty Limestone" of Picard (13; p. 188); Group E of Henson in Blake (3; pp. 28–43); "Crétacé Supérieur" (Nablus) of Romar and Doncieux (14; p. 171).

Syria.—"Craie Maestrichtienne" (upper part) of Djebel Abiad Section (7; p. 87).

Egypt.—El Moweileh Section (near El Kossaima, Sinai), chalks with Nummulitic Limestones.[1]

Iraq Basin.—"Limestones and Glauconitic Sandstones" of Imam Hassan Section (4; p. 95).

The *G. simulatilis-G. velascoensis* fauna grades up progressively into an assemblage in which sharply-keeled *Globorotalias* have largely given place to species of more rounded form, e.g. *G. crassaformis* (Galloway and Wissler). Globigerininae are still the dominant fossils, especially the large, thick-shelled, coarsely perforate and spiny species and those of the groups of *G. bulloides* d'Orb. and *G. triloculinoides* Plummer. Very small *Gümbelina* sp. are locally common. Additional Tertiary genera (*Hantkenina*, *Uvigerina*, *Globigerinoides*, etc.), make their appearance in the higher zones. "Floods" of Radiolaria and sponge spicules sometimes occur in siliceous beds.

This is the most widely distributed of the Eocene microfaunas but it often lacks positive features by which it may be distinguished from typical examples of the earlier and later Eocene. It is most frequently associated with Lutetian and Ypresian Nummulitic limestones and although its upper and lower limits are indefinite, it can always be identified with certainty as Eocene.

Upper Eocene.

Palestine.—"Upper Chalky Layers" and Beit Jibrin Series (lower part) of Picard (13; pp. 188 and 190); Group D 2 of Henson in Blake (3; pp. 28–43).

Iraq Basin.—"Globigerina Marls" (lower part) of Imam Hassan Section (4; p. 95).

In the higher Eocene the genus *Globorotalia* shows a marked decline while species of *Globigerinoides*, e.g. *G. triloba* (Reuss), increase greatly in size and frequency. Other Globigerininae are always conspicuous.

Thin sections reveal an abundance of minute *Gümbelina* which rarely appear in washed residues and must be looked for under high magnification.

Hantkenina is still characteristic and other Tertiary genera (*Uvigerina*, etc.), increase in number and variety.

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[1] This section grades down through passage beds with the "transitional microfauna" into Upper Cretaceous marls and chalks.

Oligocene.

Palestine.—Beit Jibrin Series (upper part) and Zeita-Qubeibeh facies of Picard (13; p. 194, etc.); Group D 1 (part) of Henson in Blake (3; pp. 31, 32, 43).

Iraq Basin.—" Spatangid Shales " of Imam Hassan Section (4; p. 95).

Oligocene assemblages of small foraminifera in Palestine are essentially transitional between those of the Upper Eocene and the Neogene respectively and usually lack positive features; their determination is uncertain unless the microfauna is sufficiently rich to lend weight to negative evidence.

In a continuous sequence the disappearance of *Hantkenina* and *Gümbelina* is considered arbitrarily to mark the Eocene/Oligocene contact, though these genera are known elsewhere from the Lower Oligocene.

Concurrently additional genera and species appear—*Elphidium macellum* (Ficht. and Moll), *Amphistegina* spp., etc.—while others that are rare or absent in the Eocene, become characteristic, including *Orbulina* sp., *Sphaeroidina* sp., *Textularia carinata* d'Orb., *Globigerinoides rubra* (d'Orb.), etc.

All the Oligocene forms so far recognized continue into the Neogene.

Neogene.

Palestine.—Saqiya (Sakie) Beds of Loewengart in Avnimelech (2; p. 101) and Picard (13; pp. 199–204); Helvetian ? of Picard (13; pp. 195–7); Lower Pliocene of Blake (3; pp. 8, 13); Groups B, A 1, A 2 of Henson in Blake (3; pp. 31, 32, 42).

Syria.—Pliocène ancien of Dubertret (8; p. 99, etc.).

Egypt.—Schlier of Macfadyen (11).

Several hundred species of small foraminifera have been distinguished in the Neogene microfaunas of Palestine, which compare closely with those of equivalent age described from other Mediterranean regions and particularly from the Miocene of Egypt (11). The richness in genera and species of typical assemblages at once distinguishes them from earlier faunas though unusually poor examples may sometimes lead to uncertainty. Species of *Globigerina*, *Globigerinoides*, *Orbulina*, *Sphaeroidina*, *Bulimina*, *Bolivina*, *Uvigerina*, *Nonion*, etc., are all very numerous, varied, and robust. Certain forms that are rare or absent before the Miocene become abundant and characteristic, including *Asterigerina* [*Discorbina*] *planorbis* (d'Orb.), *Nonion boueana* (d'Orb.), *Siphonina* spp., *S. reticulata* (Czjzek), *Epistomina elegans* (d'Orb.), *Planorbulina mediterraniensis* d'Orb., *Elphidium crispum* (Linné), *Rotalia beccarii* (Linné), *Borelis melo* (Ficht. and Moll) (= *Neoalveolina bradyi* Silv.).

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Problems of Ammonite Nomenclature.

1. On the Type of the Ammonite Genus *Mortoniceras*, Meek.

By L. F. Spath.

MOST workers on fossils at the present day try to conform to the International Rules of Zoological Nomenclature,[1] but there are cases in which even the most conscientious palaeontologist may be in doubt as to whether any given article or recommendation of the International Code can justifiably be applied. Some workers, I may add, are forgetting that this code should be a good servant, and must not be allowed to become a bad master; again, while others are in favour of applying to the International Commission for standardization of almost every problem, many palaeontologists feel that the rules should not be relaxed except in very special cases. It seems to me of general interest to discuss some doubtful cases; for future workers may be guided by our difficulties, and the overworked Commission will eventually benefit by the discussion.

T. W. Stanton's [2] recent note on "The Genotype of *Mortoniceras*, Meek" deals with one of these nomenclatorial problems. The genotype is *Ammonites vespertinus*, Morton; and according to article 30a of the Rules "when in the original publication of a genus, one of the species is definitely designated as type, this species shall be accepted as type, regardless of other considerations". Now nothing seems simpler, at first sight, than this case of *Mortoniceras*, and it is necessary to examine the reasons adduced by Stanton for not applying the article quoted, and for not accepting *Amm. vespertinus* as the genotype. I hope I am not misrepresenting him when I summarize his view thus: "Internal evidence points to Meek having selected *Ammonites texanus*, Roemer, as the type of *Mortoniceras*."

Now it is true that Meek added, after *Ammonites vespertinus*, in brackets (= *A. texanus*, Roemer), but this is the first in a series of errors; for clearly he should have said *A. texanus*, Gabb, a very different thing from *A. texanus*, Roemer. For Gabb's specimens came from the same locality as Morton's original type of his *A. vespertinus*, i.e. they were of Lower Cretaceous (Albian) age, and may therefore well have been to Gabb "in all respects identical with *A. vespertinus*", but they were not Roemer's *A. texanus* of high Upper Cretaceous (Santonian = Middle Senonian) age. Of course, Meek's statement that the genus *Mortoniceras* "seemed to be confined to the Cretaceous system", now appears curiously naïve, but it is just because there is so much resemblance between the Lower and Upper Cretaceous forms involved that the type should be selected "regardless of other considerations". This resemblance, of course, also accounts for a similarity of the diagnostic characters of the two groups; but the three lateral lobes mentioned in the original description of *Mortoniceras* are not found in the true *A. texanus*, nor is it the largest known Texan Cretaceous ammonite, as Shumard (1854) described *A. vespertinus*.

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[1] Reprinted in an excellent book recently published by E. T. Schenk and J. H. McMasters, *Procedure in Taxonomy*, Stanford University Press, 1936 (72 pp.).

[2] *Journ. Palaeont.*, xi, No. 5, 1937, 456–8.

Again, the fact of "Morton's figure being very defective" or "obviously inaccurate" is assailable. The large original fragment was, of course, incomplete; but in any case the reduced figure shows extremely loose coiling and very distant ribs; and palaeontologists acquainted with Cretaceous ammonites should have realized that large forms with resemblance to Morton's figure of *A. vespertinus* could occur in the Albian but not in the Senonian. Meek did not know the true *A. texanus* any more than Gabb who assured him that *A. vespertinus* and *A. texanus* were synonyms, but misidentified the latter; the defective figure of *A. vespertinus* cannot be blamed for that. Pending the redescription of Morton's species, its identity may be uncertain; but replacing an imperfectly known genotype by another, merely because it may be better known to the selector, surely is bringing in "other considerations". *A. vespertinus* has never been satisfactorily identified simply because there was no one to do it; and even now the redescription by Adkins (which I announced in 1932) appears to be held up.

Since Grossouvre and, after him, Pervinquière, merely perpetuated Gabb's error, their selection of *A. texanus* as the genotype of *Mortoniceras* (s.s.) is not binding; yet it should be noticed that palaeontologists in general were quite ready to adopt the selection. In fact, no fewer than three independent generic names were used by authors for the Albian forms left by Pervinquière in the genus *Mortoniceras*, until it was confirmed that *A. vespertinus* was an Albian form, and that the restriction of *Mortoniceras* to the Senonian *texanus* group was *ultra vires*. I cannot therefore agree with Stanton that I was in error in using *Mortoniceras* for the Albian forms, and in giving a new generic name to the Senonian *texanus* group. I venture to suggest that it is just the absence of clearness of this so-called "internal evidence" that makes it desirable in this, of all cases, to insist on the strict ruling.

REVIEWS.

LANDSLIDES AND RELATED PHENOMENA. By C. F. STEWART SHARPE. pp. xii + 137, with 9 plates and 16 text-figs. New York: Columbia University Press, 1938. Price 15*s.*

THE author of this book says in his introductory sentence that landslides (for which landslips is the English equivalent), have not received sufficient attention in geological literature. This is probably true if the term is interpreted in the widest sense. Moreover, there is found almost everywhere a certain vagueness in the definitions. The main object of the book is to remedy this by drawing up a detailed classification of a precise character, although it is freely admitted that in most cases any number of transitional forms exist, as in nearly all other geological categories. With these qualifications, the basis of the classification may be summarized as: creep, flow, slide and fall, with or without the assistance of water and ice. These terms really explain themselves. The book is clearly written and well illustrated, with a comprehensive bibliography and is well worthy of careful study by those concerned with the practical problems of field and engineering geology. The price seems rather high.

FORTSCHRITTE DER PALÄONTOLOGIE. Edited by O. H. SCHINDEWOLF. Vol. I. pp. viii + 374. Berlin: Borntraeger, 1937. Price RMk. 29.60 (unbound).

THIS new journal was originally planned as a biennial supplement to keep the proposed *Handbuch der Paläozoologie* up to date and though the publication of the latter has been delayed for various reasons the *Fortschritte* fulfils a useful purpose in itself.

Volume I, covering the years 1935–6, comprehends a review of work done in various branches of palaeontology during this period, and most of the contributors (there are twenty-one in the present volume) are well-known specialists in the subjects for which they write. The field covered comprises General Palaeontology (including text-books); invertebrate faunas (Pre-Cambrian, Palaeozoic, Mesozoic, and Cainozoic), and the principal classes of the various invertebrate phyla and of the vertebrata; and also Palaeo-, Meso-, and Cainophytic floras and the various groups of fossil plants.

The treatment by the different contributors is not uniform, but perhaps a greater uniformity will be aimed at in later volumes. Again, there appears in some instances a certain lack of balance in the space allotted. Naturally the volume of work on any of the subjects will vary from year to year, yet 17 pages on "Palaeoneurology" seems a rather disproportionately large allowance in comparison with 11 pages on Brachiopods, and 7 pages on Trilobites. Indeed, the section on Trilobites might be criticized for undue brevity, and for the omission of all reference to British work (except for a small paper by the late Dr. Cobbold) during what were, in fact, two rather prolific years. In general, however, the obvious difficulties of furnishing an adequate yet reasonably brief critical survey of two years' work have been admirably surmounted, and the new journal may be welcomed as a distinctive and useful guide to recent advances in Palaeontology.

O. M. B. B.

CORRESPONDENCE.

THE KIRMINGTON SECTION.

Sir,—It should interest all glaciologists to know that a first-rate section can now be seen in the little clay-pit at Kirmington in North Lincolnshire. No reminder is needed that this is the one spot in all England where the late G. W. Lamplugh held that there was a case for interglacial marine sediments.

When Lamplugh last wrote on this matter,[1] the all-important upper bed of boulder-clay, covering laminated shelly silts, was no longer visible, though he did not dispute its presence in earlier excavations. At a recent excursion of the Yorkshire Geological Society, led by Mr. C. F. B. Shillito, it was found that this boulder-clay had reappeared, and a knife-edge contact with the underlying gravel and sand (beneath which are the lead-coloured shelly clays) could be studied in close detail over a stretch of 20 yards or more. Although only 4 or 5 feet thick, a more typical boulder-clay could not be desired—quite unbedded, with a stiff dark red matrix, showing no signs whatever of incorporation of the underlying strata. As for the latter, certainly the top of the gravel and sand was eroded, but there was not the least trace of crumpling, thrusting, or movement of any kind. Now this is what we see in the vast majority of boulder-clay contacts with underlying sands, gravels, silts, and leafy clays, throughout North-Eastern England. Personally, I cannot see how such strata can be explained other than as a single englacial "melt", working its way upwards through the complex contents of a stagnant ice-sheet—the boulder-clay representing the englacial dirt, the sediments gathering as the "melt" made its way upwards through the clear ice patches. I exclude the apparently continuous bed or beds of "Middle Sands", which have a different origin, though they also belong to the one "melt".

The Kirmington sediments are known, through the British Association's borings, to rest on 61 feet of alternating boulder-clays and silts before the Chalk is reached. If they belong to a lens of transported material, lying near the top of this considerable sequence of glacial deposits, then it seems reasonable to look on the whole series as a single "melt", only noteworthy in that the "raft" near the top is larger than usual (though larger ones are known elsewhere). If, on the other hand, they are *in situ*, then, as Lamplugh pointed out, there must have been a marine submergence of 100 feet or more, of which no sure record exists elsewhere in Eastern England—no record, at any rate, by shells or other marine organisms. Granting such a submergence, and that lack of confirmation only marks a deficiency in observation, even then the contacts suggest that the covering boulder-clay must be englacial dirt, quietly melted out from floating ice on to the sands below. The gravel may well have come from preliminary showers of such material, small enough to be washed clean. There *are* signs of disturbance and incorporation at the boulder-clay-gravel contact in an immediately adjacent pit (we see here a zone of gradual transition, about 1 foot thick), and that this should be so in one pit and not at all in the other, surely suggests a grounding berg or an irregular melt rather than the moving-in of a whole ice-sheet.

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[1] *Trans. Hull Geol. Soc.*, vi, pt. v, 1925.

In any case, whether *in situ* or not (and I am inclined to think not), it looks as if the shelly clay of Kirmington is of late-glacial date, not interglacial. But I would like all interested to see the section as it is at present, for, in Lamplugh's concluding words, "any time spent upon the investigation of the Kirmington episode may produce results of wide consequence."

R. G. CARRUTHERS.

NEWCASTLE.
8th February, 1938.

THE ZONAL POSITION OF THE ELSWORTH ROCK.

SIR,—With regard to previous correspondence on this subject, will you allow me to point out that in my opinion Dr. Arkell is wrong in his interpretation of *Amm. cordatus* and therefore in his use of the term *cordatum* zone? Only chaos can result from Dr. Arkell's gratuitous alteration of previous revisors' work on this and other Corallian ammonites, for example, *Amm. serratus*. The reason given for wishing to alter the interpretation of the former species seems to me exactly the reason for not altering the latter. His *plicatilis* zone also is to me merely a meaningless assortment of heterochronous and incompletely known local developments. In the circumstances I am afraid that the general reader will not greatly benefit by any discussion involving these zones; but it seems clear that Dr. Arkell does not realize how incompletely Upper Oxfordian time is represented by the Corallian deposits of England. Since Dr. Arkell himself again listed species (like the two *Goliathiceras*) from the Elsworth Rock which only occur (elsewhere) in the Upper Oxford Clay and the Lower Calcareous Grit, I am afraid that I cannot alter the views that I have already expressed.

Nor am I disposed to accept whole-heartedly Dr. Arkell's corrections of the identifications given in my Kachh Memoir, for example, of the Indian species which he does not know. But, since the personal element often influences identifications, it would weary your readers to pursue the subject. Suffice to say that only the latest elements of the Elsworth Rock ammonite fauna, i.e. those which date the bed are of *transversarium* age, and that in my opinion this greatly condensed rock also includes ammonites derived from older deposits.

What I objected to principally was that Dr. Arkell quoted from my text without reference to the table round which it was written, and which would have prevented any ambiguity about the various zonal names. Such terms as "transitional" or "confirmatory" lose their significance apart from the table, where the true position of *Cardioceras rouillieri*, for example, is clearly indicated.

The phrase about the Elsworth Rock at Upware being in close association with a coral reef is a quotation and should have been printed as such. I was concerned with the ammonite succession and not with questions as to where the "rock" is supposed to be; but I did establish the *transversarium* age of the coral reef the same as I did the Elsworth Rock. The "transition beds" with *C. rouillieri*, etc., are clearly not the Elsworth Rock but the beds transitional from Oxford Clay to the (now missing) Lower Corallian, which, at Elsworth, supplied some derived elements of the fauna. There is, then, in my view, no doubt that the Elsworth Rock is really a "mixed deposit".

L. F. SPATH.

BRITISH MUSEUM (NATURAL HISTORY),
16th March, 1938.

THE FLOOR OF THE ARABIAN SEA.

SIR,—We have read with interest the recent criticism by Dr. G. M. Lees (GEOL. MAG., 1938, p. 143) of a paper on the Floor of the Arabian Sea published by us, and we would like to take this opportunity of replying to the points raised in that letter.

First, it is incorrect to claim that we state on page 223 of the GEOLOGICAL MAGAZINE for 1937 that on the Kuria Muria Islands a granite is intrusive into an overlying sandstone of *Miocene Age.* We do state that the granite is intrusive into a sandstone formation, but there is no mention on this page, or anywhere else in the paper, that the sandstone on the Kuria Muria Islands is of *Miocene Age* That the granite is intrusive was inferred by one of the authors (R. B. S. S.) both from the upward tilting of the practically horizontal strata on approaching the granite contact, and from its fragmentation at the contact. Perhaps Dr. Lees has been confused, since later on we mention that some of the sandstones and limestones along the south-east coast of Arabia are almost certainly the same age as the Makran group of sandstones; this claim was based on the report by Dr. R. D. Oldham, of the Geological Survey of India, that in the Sur Hinterland, to the west of Cape Ras al Hadd, there are thick deposits of Miocene age—a statement that Dr. Lees himself quotes in his paper (*Quart. Journ. Geol. Soc.*, lxxxiv, 610).

Secondly, Dr. Lees says that the discovery of a double ridge is an insufficient basis for the postulation of a Rift Valley. Here again there is a discrepancy between the original paper and Dr. Lees' interpretation. In the original paper we referred to the *apparent* similarity that exists between the *topography* of the floor of the Arabian Sea and the region to the west of it that is characterized by the Great Rift Valley, but we did *not* state that the double ridges are rifts.

Thirdly, we would be the first to agree that there are possible alternatives to fault scarping along the Arabian Coast, but we consider that faulting fits the facts, as they are known to-day, better than any other hypothesis. We pointed out that the soundings along the Arabian Coast are irregular and may possibly indicate submarine valleys, but since many authors consider that submarine valleys may be formed by means other than sub-aerial erosion, it would seem unwise (even if their existence had been definitely proved) to put this forward as an objection against faulting.

Fourthly, Dr. Lees claims that the ridges on the floor of the Arabian Sea undoubtedly "follow the trend of older fold systems, which according to evidence in Oman, may be of any age from Upper Cretaceous onwards". This may be so, but we would like to point out that there is no submarine evidence that the Murray Ridge has any connection with the Oman Range. The soundings in this region indicate that the Murray Ridge does not join the Oman Range at Ras al Hadd; a gap of some 70 miles with a depth of water of 1,750 fathoms separating the two.

We are in full agreement with Dr. Lees when he states that the area would repay further investigation and we are quite aware of the importance of geophysical investigations and the necessity for close collaboration between the various sciences involved. Finally, we think it is obvious to those who realize the scarcity of available data regarding the oceans, covering as they do nearly three-fourths of the surface of the earth, that any paper must of necessity be of a preliminary nature and not be regarded as a final synthesis.

R. B. SEYMOUR SEWELL.
JOHN D. H. WISEMAN.

9th April, 1938.

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ORIGINAL ARTICLES.

Density Currents in connection with the problem of Submarine Canyons.

By Ph. H. Kuenen, Groningen, Holland.

1. The Problem.

THE investigation of submarine canyons has been actively pursued in the United States of latter years, principally due to the activities of F. P. Shepard. The Coast and Geodetic Survey has mapped a large number of these interesting chasms, both along the Atlantic and Pacific continental slopes, by sonic soundings; Shepard himself added data by soundings and dredgings along the Californian coast; Stetson performed current measurements, dredgings, and sampling in the canyons off the east coast. The number of data is steadily increasing in the United States, and it is to be hoped other nations will also become active, for much still remains to be learned before a comprehensive view of the many-sided problem can be obtained.

To find a solution of the problem how these canyons may have been generated is of no small consequence to earth science. Not only do submarine canyons form the most spectacular erosive features of the earth's crust, but such revolutionary ideas as a variation in the speed of revolution of the earth, a world-wide sinking of ocean-level to the amount of 3,000 feet, and enormous currents set up by suspended silt have been suggested as possible causes for their development.

Many of these furrows running down the continental slopes are broader than the Grand Canyon of Arizona, others are fully as deep and possess no less precipitous slopes than this grandest of all subaerial valleys. Starting at the edge of the shelf or well within its outer border, they have been traced to 30 miles from their point of origin to a depth of 10,000 feet and apparently continue to the floor of the ocean, although the surveys have not been carried to the lower ends as yet. Scores of examples have already been cited in all latitudes and their distribution is world-wide. In all major respects the shape resembles that of valleys formed by subaerial erosion. There is a continuous slope seawards and they form a dendritic pattern with their tributaries. Nature here challenges scientific investigation and speculation with a baffling problem.

It would lead us too far to discuss all data and the various suggestions that have been offered as possible modes of development. The bibliography at the end of this paper may serve as a guide for finding the scattered papers dealing with our subject. Only the more relevant contributions have been cited.

The aim of this paper is to draw attention especially to the hypothesis evolved by Daly, as it is believed to constitute the most promising line of speculation. But it is fully admitted that difficulties are by no means absent and that the scepticism shown by many towards its validity is not unfounded.

Stated briefly Daly proposes the following explanation. During the glacial epoch ocean-level was lowered by 100 metres. The finer sediments building up the continental shelves were thereby brought within reach of storm waves running across the shelf and were churned up to form a dense suspension. The heavy water then started to flow out from the coast and down the continental slope to the deep sea. On the way down these currents gathered speed and eroded furrows in the slopes until after frequent repetition the submarine canyons had been cut out. After the final rise of sea-level the shelves had been denuded of their finer sediments and lowered to their present position. Relatively clear water is now maintained even during stormy weather, and consequently erosion of the gorges has ceased and they are now found to be coated by fine deposits of post-glacial origin.

Obviously this line of reasoning needs quantitative support, for although we may grant the principle, we may well doubt whether the rate of flow was sufficient to cause appreciable erosion of the bottom. Daly, therefore, attempted to calculate the velocity by using the formula

$$v = c\sqrt{msd}$$

in which v = velocity of the ensuing current, m = hydraulic mean depth (area of the cross-section divided by the wetted perimeter), s = axial slope, and d = effective density. Conservative estimates of the various values lead him to suppose that a velocity may have been obtained of 70 cm./sec. He is of opinion that this may be sufficient for the erosive work to be performed.

The present author carried out some experiments to test the general validity of the principle. It was found that a suspension will actually flow down a slope similar to that of the continents, without appreciable mixing with the overlying clear water, and that it gathers in very slight furrows on the slope. A difficulty in experiments is that the small scale greatly reduces the velocity and that consequently the suspension soon loses its initial density by dropping the silt. But analogous phenomena are obtained by substituting a solution of salt for the suspension. In this manner a constant density may be maintained and comparative data procured. The formula was thus roughly tested and found to be valid. By using a dense solution swift currents of 20 cm/sec. were set up and fine ripple marks formed in the model gorge.

It has been suggested to me that the use of a solution with effective density of 0·06, that must greatly exceed natural circumstances, weakens the value of the experimental demonstration. But this is to neglect the influence of size. Extrapolation to the size of our canyons is, of course, needed, and may admittedly cause errors. But the formula shows that dimensions are as important as density to the ensuing velocity. As the former are limited in a laboratory, the only way in which the conditions in nature can be approached is by the exaggeration of the latter (increasing the slope would be more objectionable still). By increasing the specific gravity and thus also the velocity the adverse influence of turbulence and mixing is introduced to a certain extent. If, as was found, the density current nevertheless sets through, more trust can be placed in its action at the calculated speed under natural conditions, than if merely the sluggish currents due to suspended silt had been examined in the experiments.

An illustration of these relations is that the density flow through Lake Mead attained a velocity of 27 cm/sec. On the same slope but on the scale of the experiments the velocity would have been only 1 mm/sec. The mud in such an experiment would have settled out almost directly, but in Lake Mead the current travelled for almost a week along the bottom of the reservoir, losing only a portion of the suspended silt. Had the slope in the reservoir been equal to that of a submarine canyon, the velocity would have been 170 cm/sec.

It will now also be clear that an eroding current is excluded in cases where only a small volume of muddy water can be formed. Shepard mentions examples, where recent trenches should be expected if Daly's views were correct. As they are absent he doubts the validity of the hypothesis. But in some of these cases the scale is too small for an eroding current to be generated. On the Mississippi delta the slope is only slight and the density flows formed at the present must be slow. Therefore they may deposit as much as they erode. Close to the river the silt dropped from the outflow of fresh water along the surface will also tend to obliterate the effect of slight erosion. The trough further away is of abnormal shape, being very broad and irregular. In this case mud slides may be an important factor in the formation of the gorge.

The experimental results lend support to Daly's hypothesis, not merely from a qualitative point of view, but no less along quantitative lines. It was found that a shelf area of 1,000 km^2 could have furnished enough silt to set up 10,000 currents that had a velocity of 40 cm/sec. It was also found that they must have eroded at least six times as much as they originally carried. This extra load went to increasing the velocity and magnitude on the way down. A speed of 100 cm/sec. could be expected at the lower end. It is, of course, necessary to suppose that the slopes are composed principally of unconsolidated sediments. As the current only touched the lower part of the cross-section, most material must have slid down the sides of the trough to the bottom. The same is the case with normal valleys. But while creep and rain washing are the chief agents in the latter case, the walls of the submarine valleys must have slumped whenever the overdeepening by erosion tended to raise the slopes above the maximum angle the wallrocks could support. In this manner harder strata were undermined and crumbled down in loose blocks. The erosional work of the flows was then mainly restricted to transportation of loose materials even in cases where more resistent layers crop out in the walls. The latter are most likely to be caught during dredging operations, and must give an exaggerated impression of the average firmness of the rock. Stetson's dredgings yielded few indications of resistent layers in the canyons of Georges Bank. Shepard, however, came to the conclusion that the Californian canyons have relatively firm walls. It is tentatively suggested that this impression is not final proof.

2. DENSITY CURRENTS IN RESERVOIRS AND SUBMARINE CANYONS.

So far I have merely given a brief summary of former results. We must now turn to some new developments. Inadvertently man has performed experiments on a much grander scale than those just described. Daly already drew attention to the furrows sounded in deltas in Switzerland, due presumably to the action of silt-laden water flowing into the lake. He kindly pointed out to me that more precise data have been obtained by silt measurements in artificial lakes, the most outstanding example being furnished by Lake Mead formed by the construction of Boulder dam in the Colorado river. An extensive campaign is now being pursued in the United States in connection with the study of the silting of reservoirs and before long a large body of significant data will be at hand. Although the main object is to study economic aspects, the investigation of silt currents in general will be greatly furthered. It may appear premature, when so much is to be learned in the near future, to attempt an analysis from our point of view of the data already at hand. But these already give significant indications of what may be expected, and it is hoped that the present paper may stimulate research in other regions and draw attention to those aspects that may be of paramount importance to the explanation of submarine canyons, aspects that might otherwise escape notice during the present investigations and thus be neglected to the disadvantage of oceanographical geology and also of engineering science. This may excuse the present attempt, and the author is fully aware of the fact that in the near future corrections will be found necessary on the present results. Stimulation of research and not capitalization of present knowledge is the aim of this paper.

The case of Lake Mead may now be examined more closely. It was observed that some days after a sudden rise of the amount of suspended sediments at Grand Canyon above the reservoir, muddy water was discharged at the temporary outlet gates at the bottom of Boulder dam, although the surface water in the lake remained uniformly clear. Evidently the dense suspension dived under the lighter, clear waters of the lake and flowed along the bottom in the original bed of the river until it reached the lowest point at the gates. From this it follows that the dense suspension flowed under the clear water without appreciable mixing, although the slope was very small. It also follows that part of the silt remained in suspension notwithstanding that the flow lasted many days and was comparatively slow. To gain a rough estimate of the value of the constant c in our formula the following data are available.

For eight flows or impulses the average time from Grand Canyon gauging station to that of Willow Beach just below the dam, for the period from March to September, 1935, was $7\frac{1}{4}$ days. For these eight flows the average time from Willow Beach to Topock was $1\frac{1}{2}$ days; average speed below Willow Beach 70 miles per day. The distance from Grand Canyon to the lake is $265 - 80 = 185$ miles, so the muddy water will have needed $2\frac{1}{2}$ days to cover this stretch. Taking 27 cm/sec. for the flow in the lake, it would have needed $5\frac{1}{2}$ days to run the whole length. This appears to be a conservative estimate of the rate of flow through the lake.

For these eight flows the average percentage weight of suspended matter at Grand Canyon was $2{\cdot}57$ per cent, giving a specific gravity for the suspension of $1{\cdot}016$. The average discharge was 12,000 cubic feet or 340 m^3. With a speed of 27 cm/sec. the area of the cross-section in the lake must be 1,260 m^2. Assuming a breadth of 126 m. and a depth of 10 m. the hydraulic mean depth is 460 cm. The slope was $0{\cdot}0007$ (see *Proc. Am. Soc. Civ. Eng.*, 1937, p. 1410). Filling in these values in our formula:

$$v = c\sqrt{msd}$$

$$27 = c\sqrt{460 \times 0{\cdot}0007 \times 0{\cdot}016}\,; \quad \text{hence } c = 375.$$

In the Elephant Butte Reservoir the underflow attained a speed of 60 cm/sec. on a slope of 1 : 1000 in consequence of the high density (about 10 per cent of solid matter by weight), see Bibl. 2, pp. 7, 10, 77, etc. If the discharge was of the order of 1000 m^3/sec. and the hydraulic mean depth 300:

$$60 = c\sqrt{300 \times 0{\cdot}001 \times 0{\cdot}08}\,; \quad \text{hence } c = 385, \text{ probably more.}$$

In my experiments the hydraulic mean depth was not accurately known; I believe it to have been between $\frac{1}{4}$ and $\frac{3}{16}$.

$$10 = c\sqrt{\tfrac{1}{4}\,(\tfrac{3}{16}) \times \tfrac{1}{8} \times \tfrac{6}{100}}\,; \text{ hence } c = 230 \text{ or } 270.$$

It is seen that the case for Lake Mead and probably also of Elephant Butte reservoir give a higher value for c, or in other words would give a higher velocity when applied to submarine canyons than was supposed in my former paper. True, with the higher velocity for these features turbulence would reduce the factor c. But on the other hand silt settled out during the leisurely flow through Lake Mead, thus reducing the average value of d in our formula. If we had used the density of the current at Willow Beach (0·86 per cent):

$$27 = c\sqrt{460 \times 0{\cdot}0007 \times 0{\cdot}0054}\,; \text{ hence } c = 660.$$

Probably this is nearer the correct value, and consequently in using the value 400 in the case of submarine canyons ample allowance for the adverse influence of turbulence has been made.

For the Colorado river above the lake we get:

$$130 = c\sqrt{200 \times 0{\cdot}0007 \times 1}\,; \text{ hence } c = 325.$$

But this figure is doubtful without exact data on the slope and cross-section of the river.

The value of $c = 400$ may now be used in calculating the velocity for submarine valleys. Assuming the depth to be 100 m. (in my experiments it was always more than the depth of the water on the shelf) the formula reads:

$$v = 400\sqrt{2500 \times \frac{1}{15} \times \frac{1}{10{,}000}} = 50 \text{ cm/sec.}$$

Thus with an extra density of 0·0001 the speed is large enough for the current to start taking up silt and gaining velocity. It is of importance to note that formerly on the basis of my experiments a density of 0·00028 was needed to obtain 40 cm/sec. The new data are seen to make the case for Daly's hypothesis considerably stronger.

In the meantime Stetson and Smith have drawn attention to an important aspect of the problem, that becomes even more significant now that smaller densities are believed to have sufficed for causing a flow. In consequence of the density stratification of the oceans the waters on the shelf will have a lower specific gravity even after mixing by a storm than the undisturbed water deeper down. After mixing, the water on the shelf may have possessed a density of 1·026, while at 200 m. the density was 1·027. In different climates the variation is about the same, but the absolute values are slightly altered.

Nothing much will have happened during a storm until the silt raised the density of the shelf waters to 1·027. But a very slight further increase of 0·0001 then breaks through the density stratification with a velocity sufficient to start erosion. We are still far below the amount of silt Daly thought possible in churned up shelf waters (namely 0·01).

In my former paper it was shown that even with a shelf area of 1000 km.² to feed a canyon, at least six times the amount of silt washed off the shelf must be eroded from the gorge. At the lower end the excess load would be about 0·004, and as the volume will have increased through turbulence the hydraulic mean depth will not have diminished much. Hence the velocity:

$$v = 350\sqrt{2000 \times \frac{1}{15} \times \frac{1}{1000}} = 130 \text{ cm/sec.}$$

We have assumed a smaller *c* because the velocity is greater.

In the case of the Colorado River the density due to silt is 0·016 or forty times as much, when the river flows at 130 cm/sec. If we allow a similar amount of suspended matter for the case of the density current through a submarine canyon, then a smaller number of flows and consequently a smaller area of shelf is needed to feed them. But if we do not need 1000 km.² but only for instance 100 km.² the case is considerably strengthened for the Californian canyons. One of the main objections so far was that for these cases the narrow shelf did not appear to give sufficient silt to cause large flows. This objection is now largely met with.

As a matter of fact the part played by the shelf is now thought to be that of the ringing voice loosening an avalanche. If the density of a comparatively small volume of water is once raised above that of the deeper strata, the flow is set off. It gathers volume and speed on the way down and takes up more and more silt. Given a little help the canyon erodes itself. If this were not the case the flow would soon be saturated and could not continue to erode further along its course.

The density stratification of the oceans has two important influences on our problem. In the first place it holds up the flow for all cases in which sufficient silt is not churned up and this reduces the squandering of silt to some extent. Practically every time the density is raised as much as 0·0010 it will also go as far as 0·0011 and start a flow. Soon after it falls below 0·0010 the current in the canyon will stop.

In the case of reservoirs and lakes this influence is generally absent. The flow will continue and will also set in when little silt is suspended. Consequently a slow current creeps along the very slight slope at so small a speed that the silt settles out on the way. This causes silting up of the original channel.

The density stratification also explains why no erosion in the canyons takes place at present. The amount of suspended silt above the present deep shelves is not sufficient even during a storm to break through and cause a flow.

Shepard raised several objections to Daly's hypothesis (Bibl. 12). Some of these have been answered in my former paper and others have been met or lessened in strength by considerations in this article. It is beyond the scope of this paper to analyse all Shepard's remarks separately. It is admitted that difficulties still remain and that the hypothesis of density currents as the cause of submarine canyons is still open to doubt. That slumping is also an important factor is highly probable, not only in the sense of carrying materials from the walls to the bottom of the gorge, but also down the canyon. This idea was first proposed by Shepard and he recently brought important evidence in its favour. He actually followed slides from the canyon walls. In the opinion of the present author a combination of the two principles may ultimately lead to a satisfactory explanation.

In conclusion an experiment may be suggested. In some reservoirs the density flow may attain so great a velocity that the water is not carrying the maximum load of suspended matter possible with that speed. The current would then cause erosion. But this would be obscured by deposition during sluggish flows as mentioned above. If a thin layer of coloured sediment were strewn in a band across the channel, it appears possible to show by sampling that the coloured stratum is at first found on the bottom, but that later it has been carried away in the channel after one of the swifter silt flows.

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A Melt-water Hypothesis of Cirque Formation.

By W. V. LEWIS.

(PLATE VII.)

HISTORICAL.

THE Bergschrund Hypothesis, when it was enunciated by Willard Johnson (1)[1] at the end of last century, was almost universally welcomed as an explanation of cirque formation. Since that time it has continued to dominate the literature on glacial sculpture. Gilbert (2) and Hobbs (3) in America, Wright (4) in this country, and Penck (5) and de Martonne (6) on the Continent follow his ideas with only very minor modifications. The essentials of this hypothesis were, however, outlined by W. M. Davis (7) contemporaneously with the publication of Johnson's 1899 paper.

Johnson descended 150 feet to the bottom of a deep bergschrund, the crevasse series which generally opens at the head of a glacier in summer between the stationary and moving ice, at which point he found that it reached the cirque wall. Here he noted that the face of the rock was much riven and shattered, that some of the blocks were just loose, others were balanced half-way between the rock wall and the ice, whilst still others were frozen solid into the glacier ice and being moved slowly away. This observation led him to suggest that the temperature changes in the crevasse in summer caused alternate freezing and thawing of moisture in the rock crevices. This led to the disintegration of the exposed section of the rock face. The material thus loosened was removed by becoming incorporated in the moving ice of the glacier. Thus the foot of the bergschrund, and this zone alone, was assumed to be a zone of excessive erosion. It was soon realized, however, that cirques have been sculptured to depths far exceeding those of the deepest bergschrunds. So it was assumed by later writers (5) that erosion at greater depths resulted from the abrading action of the ice laden with the rock debris derived from the foot of the bergschrund. This latter aspect of glacial erosion has long been understood in view of the familiar evidence of the smoothed and fluted nature of rock surfaces which have been subjected to glaciation.

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[1] Numbers in parenthesis refer to list of references at end of paper.

It is only fair to add that observations almost precisely similar to those made by Johnson had been made long previously by Lieutenant Lorange (8) of the Survey of Norway, and their significance fully appreciated by such authorities as Helland (9) and Harker (10).

The Bergschrund Hypothesis has been attacked in certain quarters, notably by Priestley (11), who, as a result of his work in the Antarctic, realized that bergschrunds are not always present. A more serious criticism, however, was that cirques, the precipitous back slopes of which attain 3,000 to 4,000 feet in height, could not be accounted for in this manner. Bowman (12) similarly remarked on the absence of bergschrunds in many of the Andean cirques and states that Johnson himself had more or less discarded the hypothesis before his death. More recently Odell (13) has joined in criticizing this hypothesis, chiefly in view of the testimony of Klebelsberg (14) that melt-water was absent from bergschrunds encountered during military tunnelling operations in the Eastern Alps in the Great War.

One cannot leave the question of past literature on glacial erosion without referring to the work of Garwood (15), that resolute exponent of glacial protection. His views on the formation of the Alpine valleys are obviously worthy of most careful examination, but in the problem of cirque formation his contribution is unconvincing. He considers that, in the main, they are old tributary valley heads which have been only superficially modified by ice action. The crux of his theory of glacial valley sculpture is that most of the down cutting can be attributed to erosion by streams emerging from the glaciers in immediate post-glacial and inter-glacial times. This explanation can have little or no application at least in the case of British cirques, for they occur so near to the watershed that they have not now and never could have had very great quantities of water flowing in them. Furthermore, as has been testified by Harker (10) in the Cuillins and can be repeatedly noted in the British Isles, stream erosion in post-glacial times has frequently failed to fret in the smallest degree the smoothed rock surfaces at the floor of the cirque. The streams themselves are little more than trickles by comparison with the size of the cirques which they occupy and as the streams dwindle towards their sources the great amphitheatres in which they lie have been incised more and more deeply into the ancient upland surfaces.

SOME BRITISH CIRQUES: 1. CADER IDRIS.

One of the finest cirques in the British Isles is Cwm Cau on the south-east side of Cader Idris (Text-fig. 1). It is surrounded on three sides by rock walls varying between 1,000 feet and 1,500 feet in height. The east-facing head-wall and the southern slopes consist of the Upper Acid division of the Llandeilo Series (16) which dip steeply to the south. These beds consist of a complex series of ashes and lavas of intermediate to acid composition with occasional intercalations of slaty material, all of which have been more or less affected by silicification. The vertical nature of the head-wall suggests that the series is highly resistant.

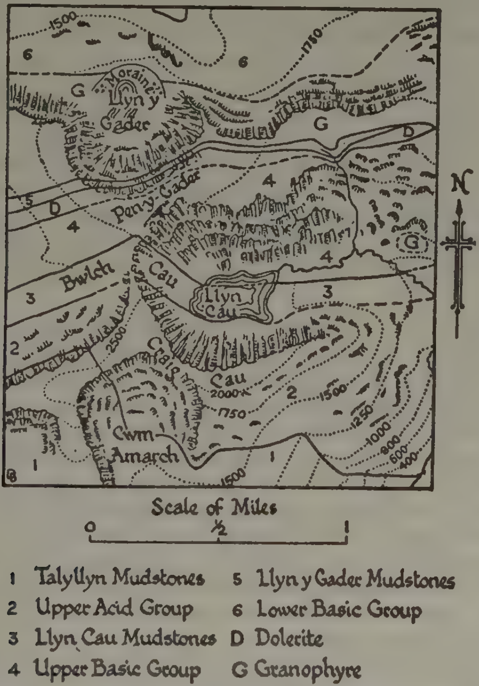


FIG. 1.—Cader Idris; based on A. H. Cox, 1925.

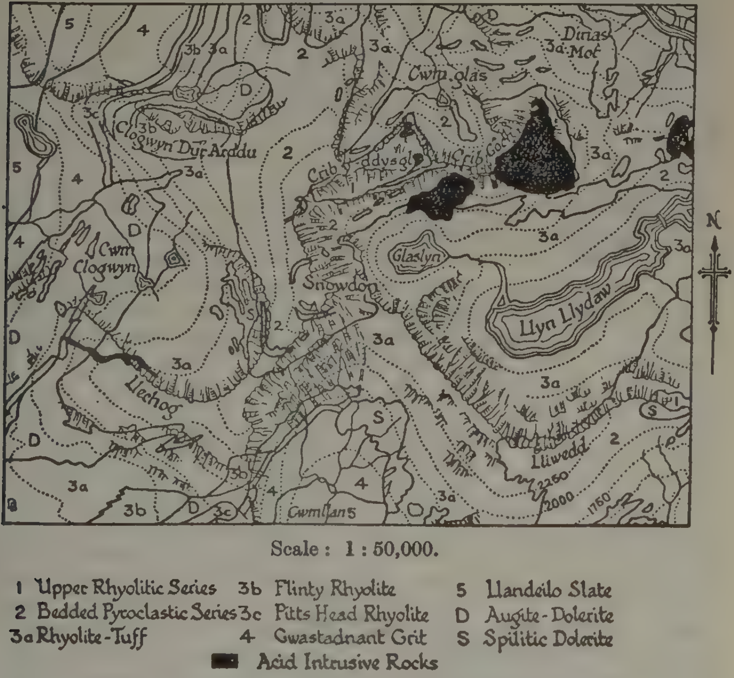
Running east-west and occupying most of the floor of the cirque are 500 feet of grey-blue Llyn Cau Mudstones. They show strong cleavage and probably present a line of weakness along which the cirque has been excavated, for the head-wall is both lowest and least precipitous where these beds crop out on either side of the indistinct pathway leading up to Bwlch Cau. The cirque floor is, however, considerably more extensive than this outcrop and transgresses particularly on to the pillow lavas of the Upper Basic Group which ie to the north. The cliffs on the north side, rising over 1,500 feet to Pen-y-Gader, closely follow the dip slope of this group and are ess precipitous than either those at the head or those on the south ide.

The head-wall is exceptionally steep, rising 1,100 feet vertically in a horizontal distance of 200 yards. The cliff face is riven and shattered right to its foot, where, owing to the almost complete absence of scree, it can be examined only 40 feet above the lake. The latter does not seem to be of any great depth so that the head-wall seems to flatten out quite suddenly forming an L-shaped angle at its foot. Less than a quarter of a mile from the head, especially on the north side an extensive area of rock face is glacially smoothed. The juxtaposition of shattered and smoothed rock suggests that the shattering was done by the ice itself and is not due merely to post-glacial weathering, a conclusion supported by the scarcity of modern scree, what little exists being largely vegetated. Further, the shattered and riven rock face is covered with mosses and lichens, the only exception being certain of the gulleys which have some modern scree material streaming from them. This stands out very clearly from the older partially vegetated scree by virtue of its lighter colouring. The lake is dammed by morainic material, beyond which the valley floor falls in level by means of a series of roches moutonnées, many of which take the form of miniature steps.

Cwm Cader on the north side of Cader Idris presents an instructive comparison with Cwm Cau. It is eroded mainly into the resistant granophyre sill which forms the fine northern escarpment of the range. At the cirque head, above the granophyre, outcrops first about 400 feet of Llyn y Gader Mudstones, a relatively soft series, then a resistant dolerite sill which is in turn surmounted by the Upper Basic Group which forms Pen-y-Gader itself. The slopes of the head wall at first rise gently and consist of largely vegetated drift and scree through which a few glacially smoothed rock outcrops appear, but soon they meet abruptly a precipitous cliff, 800 feet in height. This cliff, which is shattered to its base, is steepest on the granophyre, it recedes somewhat at the outcrop of the softer mudstones but rises sharply again at the dolerite sill. Modern scree is fairly restricted in amount except at the foot of the Foxes Path where it forms a great scree shoot. The presence of both smoothed and shattered granophyre suggests here as elsewhere that the shattering is largely a heritage from glacial times, and not merely due to post-glacial weathering, as otherwise the smoothed outcrops would also have suffered.

2. SNOWDON.

Snowdon is surrounded by a fine series of cirques (see Text-fig. 2), the deepest of which are Cwm Glaslyn and Cwm Llydaw (Pl. VII) on the eastern side. The southern cliffs and the floor of Cwm Glaslyn are formed of Rhyolite Tuff (17), the uppermost of the Lower Rhyolitic Series of the Snowdon Volcanic Suite. The east-facing head is composed mainly of interbedded potash-rhyolites and fossiliferous sediments of the overlying Bedded Pyroclastic Series and on the northern slopes this is in turn overlain by the potash-rhyolites and tuffs of the Upper Rhyolitic Series. These two series are interspersed with intrusions of spilitic dolerite and a large mass of acid intrusive rocks north-east of Llyn Glaslyn. The precipice at the head of the cirque falls 1,600 feet from the summit of Snowdon to Llyn Glaslyn in a horizontal distance of 400 yards; its face is much riven and shattered to the base, where it plunges steeply into the lake with relatively little scree material. The 1,000-ft. cliffs at the head of Cwm Llydaw fall even more precipitously from Y Lliwedd down to Llyn Llydaw and are much shattered, though the adjacent southern slopes are glacially smoothed except for a few hundred feet at the top where Rhyolitic Tuff, which forms almost the whole of this cirque, is replaced by the Bedded Pyroclastic Series.



Scale: 1 : 50,000.

FIG. 2.—Snowdon; based on H. Williams, 1927.

Cwm y Llan is incised deeply into the south side of Snowdon. It has relatively gentle slopes on the north-east and east sides, but those on the north and north-west descend abruptly from Snowdon for nearly 2,000 feet. These cliffs remain steep and shattered down to the point where they flatten out into the floor of the cirque, the angle being clearly visible owing to the sparseness of scree. Llandeilo Slates, Gwastadnant Grit, rhyolite, metamorphosed dolerites, Flinty Rhyolite, Rhyolite Tuff, and the Bedded Pyroclastic Series outcrop in this cirque, the configuration of which bears no relationship to this exceedingly complex geological structure.

Cwm Clogwyn, west of Snowdon is eroded mainly into the Rhyolite Tuff, though spilitic dolerite appears in the eastern slopes and these are capped by the Bedded Pyroclastic Series of Snowdon summit. These cliffs are not as steep as those in the other cirques and in places screes rise to the crest of the ridges, as in the case of the Llechog slopes.

Cwm Glas, on the north-east flank of Snowdon, is cut mainly into the Bedded Pyroclastic Series, though the underlying Rhyolitic Tuff appears as a window in the floor of the cirque. The Upper Rhyolitic Series form the upper part of the south-west wall and the great acid intrusion of Crib Gôch forms the south-east wall. This latter is exceedingly steep and shattered for quite 800 feet and has considerable quantities of scree below.

The cliffs forming the southern wall of Cwm Du'r Arddu present a further example of precipitous cliffs, shattered right to their base and which flatten out quite suddenly into the cirque floor. The geology of this face is unusually complex, presenting the three lower subdivisions of the Lower Rhyolitic Series, together with tuffaceous fossiliferous limestone and dolerite, and is further diversified by faults and thrust zones. Considerable quantities of scree are present but they do not entirely conceal the vertical and shattered nature of the lower cliff. This cirque is very asymmetrical, the northern slopes being only feebly developed.

Cwm Idwal, at the head of the Nant Ffrancon Valley is composite both in form and structure. It faces north-north-east and has been eroded along the axis of the Idwal syncline (18) which shows up clearly in the cliffs of andesitic basalt, pumice, and rhyolite tuff at the head of the cirque. These cliffs are precipitous and then follows a more gentle slope of coarse and largely vegetated scree, through which appear occasionally smoothed rock outcrops, which continue for the remaining 700 feet down to the lake. On the south side, however, above the Idwal Slabs, cliffs of rhyolite tuff rise sheer for nearly 1,000 feet. In places these cliffs are glacially smoothed where, almost at lake level, they plunge steeply below the superficial deposits. On the north side of the cirque the cliffs are again steep but not precipitous and show glacial smoothing to great altitudes.

Immediately east of Cwm Idwal is the higher Cwm Bochlwyd, the head wall of which rises to Glyder Fach. This cliff is again composed of rocks from the Lower Rhyolitic Series, but only the upper 800 feet is precipitous, the lower 600 feet down to the lake consisting of vegetated scree down which recent waste is sludging under spring solifluction. Rock outcrops appear, however, even at the foot of this 1,400 foot slope which are much riven and shattered presumably during glacial conditions.

3. The Cuillins.

The most magnificent glacial mountain scenery in the British Isles is in the Cuillin Hills of Skye (Text-fig. 3). The variety of frost-shattered peaks, serrated knife-edge ridges, glacially smoothed rock surfaces, deeply sunk corries, steps, and heavily-glaciated valleys renders the area ideal for the study of glacial erosion. A series of well-developed cirques scallop the south-western margin of the mountain mass. They differ from the preceding examples in the direction they face, and in that they do not occupy the sides of glacial valleys. The geology is also quite distinct, the mountains being composed of gabbro, basalt, and some peridotite. Finally, as pointed out by Harker (10), they have been subjected to intensive glaciation, both mainland and local ice having covered the area to a depth of 3,000 feet, thus surmounting all but the topmost peaks and ridges. The unusual abundance of bare rock faces, free from the usual encumbering vegetation, drift, and scree, greatly facilitates observation.

The floor at the head of Coire Lagan is at a level of 1,850 feet and is still 1,400 feet below the tops of the surrounding peaks (Pl. VII, Fig. 2). The head-wall rising to Sgurr Mhic Coinnich is a 1,200-ft. cliff of gabbro, riven and shattered at its base, though, at intermediate levels, there is a certain amount of smoothing. These cliffs have very little scree below them but on the north side is a massive scree slope rising unbroken by rock outcrops for 1,000 feet. There is a certain amount of modern streaming on this slope and the general appearance is that of a moderately fresh scree. The cirque floor and lower portions of the side walls are very highly smoothed. The transition from smoothing below to shattering above is very distinct half-way up the 1,400-ft. wall rising from Loch Lagan to Sgurr Alasdair.

The lake at the head of Coir' a' Ghrunnda is between 700 and 800 feet below the surrounding peaks and here the geological structure, which presents more variety than in most of the other corries, clearly exerts a considerable influence on the corrie pattern. Sgurr Alasdair descends in precipitous basalt cliffs several hundred feet high but the slope decreases near the gabbro junction, below which the gradient affords comfortable scrambling down to the loch. Sgurr Dubh na Da Bheinn, which dominates the lake on the north-east side, consists of peridotite and, although the slope is precipitous save for some very coarse scree at its base, it gives the appearance of undergoing rotting and shattering at the present time.

Coire na Banachdich, immediately north of Coire Lagan, faces due west and although it is sculptured deeply into the highland its slopes are not on the whole as precipitous as those of its neighbours. The southern slopes form an exception as they are precipitous for well over 800 feet and present an instructive combination of smoothed

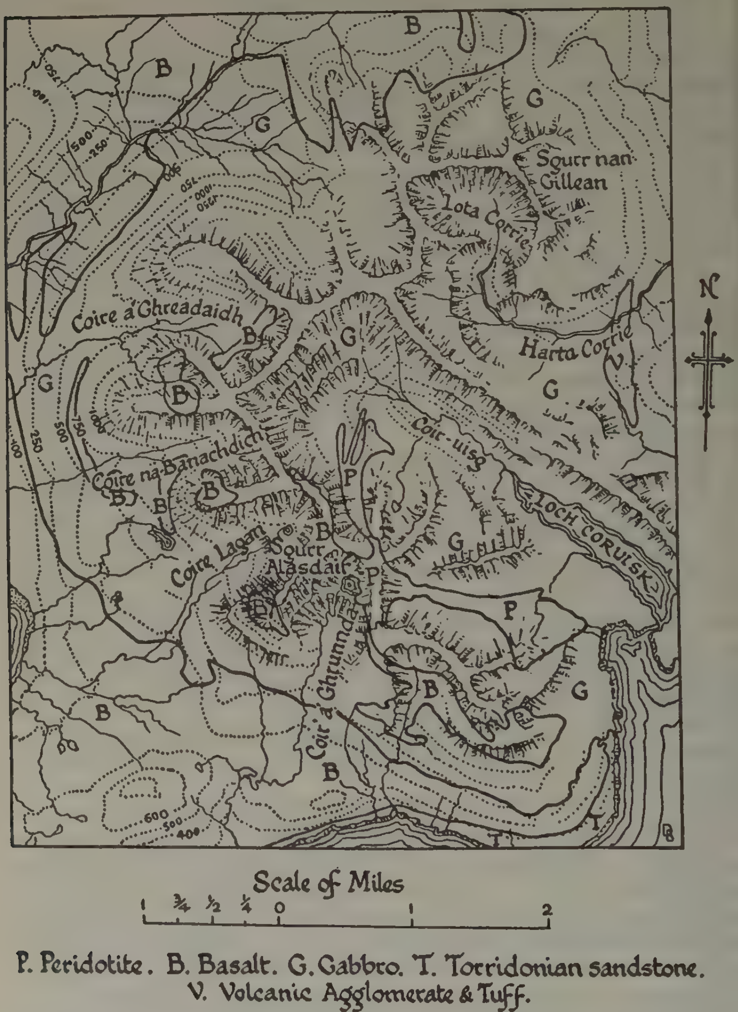


FIG. 3.—The Cuillins; based on one-inch Ordnance Survey and one-inch Geological Survey (Old Series) maps.

and shattered rock faces, these latter faces appearing a good 600 feet below the upper limit of smoothing and only a few hundred yards apart horizontally. The northern slopes have much scree material at their foot, some of which seems to be modern. The broader and lower floor is vegetated but at its head is a feature which has been referred to in many cirques, notably Cwm Cader, Cwm Glas Mawr, Cwm Bochlwyd, and Coire na Ciste below Ben Nevis. This is the occurrence of one or more rounded rock outcrops emerging from beneath the debris immediately below the head-wall. In certain cases the downstream slope is plucked, but generally it is smoothed. On the downstream side the ground level is usually well below that towards the cirque head, the feature thus forming a miniature step. The repeated occurrence of these rock outcrops is worthy of note, not so much because they form a striking feature of the landscape, but because they exist just where one would expect the scouring action of the ancient glacier to have been a maximum owing to the great thickness of super-incumbent ice.

Coire a' Ghreadaidh, the next one to the north, also has a westerly aspect, but in this case the cirque has subdivided into three. The southernmost, Coir' an Eich, is least developed, but the remaining two, Coire an Diallaid and Coire na Dorus, have very steep head-walls with a relatively sudden change to a flat floor. Most of the rock is gabbro, intruded by numerous basalt dykes, and Text-fig. 3 shows a basalt intrusion at intermediate levels which, however, does not appear to have influenced the corrie form. There is a remarkable absence of scree, so that the bare rock surfaces give the appearance of having remained entirely unaltered since they were vacated by the ice. In both instances the steep back slopes are little less than a thousand feet, then comes a tread followed by a riser, the rock being much smoothed. After a further level interval, a final drop, again strongly smoothed, leads down to the floor of Coire a' Ghreadaidh. The shattering of the cirque walls has taken full advantage of any dykes and sills which have formed lines of weakness, but only in one place, below a spectacular rock face between the southernmost and central corries, is there any scree material to suggest recent frost action.

Lota Corrie is excavated in gabbro and forms the southern slopes of Sgurr nan Gillean. It is rather larger than those already mentioned, but it shows similar characteristics. The head-wall is precipitous for 1,000 feet or more and is much riven and shattered. It merges below into gentler slopes where glacial smoothing predominates, but shattering is still present often more than 1,500 feet below the upper limit of ice action. In its relationship to the general topography, however, Lota Corrie is different, for it forms the uppermost of three cirques aligned one above the other, which form the upper reaches of a short, but maturely glaciated valley. Its strong resemblance to the earlier instances does, however, suggest that it should be included in the same group. In fact the arrangement of British cirques seems to indicate that there is no essential difference between cirques which form the head of glacial valleys and those which occur independently on the sides of a mountain mass. Helland (9) stressed this point, though Penck (5) considered that the two should be differentiated.

The greatest cirque in the Cuillins is Coir-uisg, the head of which falls unbroken from over 3,000 feet almost to sea-level. It is again excavated in gabbro into which have been intruded countless basalt dykes and sills. The uppermost 2,000 feet are precipitous and show the inevitable shattering, but below that the rock face is largely concealed by vegetated scree.

Thus the cirques of the Cuillins repeat, with slight modifications, the features present in Wales, the shattered head-walls with precipitous slopes usually to 1,000 feet or more below the uppermost limits of the ice. These steep slopes then flatten out rather suddenly into the cirque floor, though there are often minor steps below. This L-angle at the base of the head-wall is well marked in Coire Lagan and Coire a' Ghreadaidh but is less definite in some of the others and also smoothing is conspicuous. This latter is probably due in some measure to the nature of the rock, as well as to the severity of the glaciation. For, frequently, boulders of gabbro were noted weathering with a marked conchoidal fracture whilst certain of the slabs near the head of Lota Corrie were seen to have naturally smoothed and slightly wavy surfaces as they emerged from beneath the overlying beds. However, even if due allowance is made for these factors, there still remains an unusual amount of glacial smoothing in the area at high altitudes. The very great amount of smoothing shown in the base of the cirques and at lower altitudes is, of course, quite normal.

4. Ben Nevis.

The complex series of cirques in the north-east face of Ben Nevis contains all the features mentioned above. The cirque walls rise sheer for over 1,000 feet and are composed of hornblende-andesite lavas. They are as precipitous as, and more highly riven and shattered than, any of the preceding examples. There is little scree at the bottom and the cliffs flatten out quite suddenly into the cirque floor which, in the case of Coire na Ciste is sufficiently flat to contain three lakelets, though beyond this the floor falls rapidly and is glacially smoothed. At the foot of these cliffs are some of the semi-permanent snow patches associated with Ben Nevis. Again the juxtaposition of smoothed and plucked surfaces emphasizes the fact, already demonstrated by the sparsity of scree, that little change seems to have occurred since the ice left the region.

Three facts emerge from the above analysis which do not seem to be accounted for by the bergschrund theory of cirque sculpture. Firstly the head-walls with few exceptions are shattered right to their base, that is, to a depth exceeding that of the deepest bergschrund. Secondly this head-wall repeatedly meets the floor of the cirque at a sharp angle, and thirdly near this angle there frequently appears a projecting node of rock. Text-figs. 4 and 5 summarize these points, Text-fig. 4 giving the longitudinal profile that one would expect to find on the bergschrund hypothesis, and Text-fig. 5 the profile representative of the British cirques to which reference has been made. The key factor is the shattering, and this is no new observation. Lorange (8), who, in the matter of cirques, was so far ahead of his time, states: "On examining the interior of an empty cirque, we observe that a bursting, not a scooping out, of the rocks has taken place." Harker (10) also refers to the importance of the tearing away of rock in glacial erosion as evidenced by the large proportion of boulders to matrix in glacial accumulations.

THE MELT-WATER HYPOTHESIS.

In 1932 the writer spent seven weeks on and around Vatnajökull in South-East Iceland and during that time was most forcibly impressed by the amount of melting on the ice-cap in summer (19). This was greatly augmented near the margins where the black volcanic dust acted as a ready absorbent to radiation and the ice surface became fretted by a maze of melt-water streams. Priestley (11) refers to such melting in the Antarctic taking place near rock outcrops with an air temperature far below 0° C. The volume of melt-water in Iceland varied greatly from day to day, almost drying completely on a clear night and flowing strongest on rainy days. On one occasion it rained, hailed, and snowed for four days and when we left our tents we found them perched on a little platform 1 foot to 18 inches above the general level of the ice-cap. Four days' precipitation plus at least 1 foot of the surface of the ice-cap had disappeared. At the six points where the water dripped off our tent-cords holes rather over an inch in diameter had been melted into the ice. Some over-eagerness to investigate their depth led to a portion of a tent-pole being dropped down one of them and we were delayed six hours in digging it up. One might well ask what becomes of all this water. When the surface consisted of *névé* it melted its way downwards immediately and was lost to sight, but on hard ice it usually flowed over the surface for some distance until it came upon a crevasse, when sooner or later it melted its way down through the ice. This happened in some cases when the crevasse was so small that it was hardly visible until widened by melting.

Reverting to the questions of cirques, one is led to inquire what happens to all the summer rain that falls on the cirque walls above the level of the ice and the resulting melt-water from the winter snows which cling to these upper slopes. From observations made in the Antarctic by the Rev. W. L. S. Fleming (20) and those made in the summer of 1937 by the writer on a further visit to Iceland, it is evident that the water mostly melts its way down the back wall of the cirque without even flowing on to the glacier proper. If, on the other hand, it does so in certain cases, it rarely crosses the bergschrund series, but there melts its way to the bottom of the glacier. Such a supply of melt-water is only partly confined in distinct streams, the remainder being distributed along the arcuate face of the cirque in countless trickles all converging on the centre of the cirque floor. At night and during colder spells, however, this supply is much reduced and only the larger streams continue to flow.

Thus here we have a mechanism by which the cirque wall gets periodically wetted to very considerable depths. Then just as regularly the supply is partly or wholly cut off and much of the moisture freezes. In this way the rock face is disintegrated in the manner observed by Johnson, but over a far greater area of the head-wall than he had visualized. The blocks are removed by becoming frozen into the moving ice and thus drawn slowly away and here we come to a second factor of primary importance. The plucking away of the loosened blocks will be most active when the rock face is steep and the ice moves more or less directly away from the wall. It will be less active on gentler slopes where the motion of the ice is more nearly parallel to the ground, in which case abrasion and smoothing will probably be dominant. Thus steep rock faces are particularly vulnerable and so will tend to be preserved and even extended by this form of glacial plucking.

The importance of melt-water does not seem to have been realized in the past, though de Martonne (21) suggests that it might assist disintegration of the bed rock near the side of a glacier. In a recent paper Odell (13) also partially subscribes to the above views. The advantage of this suggested explanation of the mechanism of cirque erosion is that it can account for the shattering of cirque walls to very great depths below the ice surface. It can further account for the marked angle at the junction of the head-wall with the floor, for this marks the lower limit of plucking and the point at which abrading of the cirque floor begins. Both these features are of major importance, at least in the case of British cirques. It also accounts for shattering immediately above the level of the bergschrund and thus might explain the uniformly shattered appearance of the whole of the head-walls. Johnson observed this plucking and sapping at the one point where the cirque wall was accessible, but judging from the appearance of the examples described above he would have observed a similar action proceeding at considerably greater depths had such points been accessible.

In criticizing the bergschrund theory one must not take too static a view of the position of the schrundline as might be suggested by Text-fig. 4. For each winter the crevasses become filled up and open again in spring at a slightly different point. Also in the course of a long glacial period the surface of the glacier would rise and fall with varying conditions of supply and wastage. Finally, in the last phase of retreat as the whole volume of ice in the cirque shrinks, the bergschrund would steadily traverse the whole of the lower part of the cirque wall and therefore might leave it uniformly plucked. This might well account for merely superficial plucking, but could hardly be responsible for the removal of the vast amount of material necessary to form the L-angle at the foot of the head-wall. For such an assumption would attribute the major sculpturing of the cirque to the action of a decadent cirque glacier. Further, such a glacier would end either in the cirque itself or on the valley floor below, and would therefore leave great deposits of coarse material near at hand. Small morainic dams do occur in some cirques, but they form only an insignificant proportion of the whole amount excavated. Thus it seems more reasonable to assume that the major proportion of the sculpturing and the consequent removal of material is attributable to a time when the glaciers were of sufficient magnitude to transport their load to regions far removed from the sources of supply.

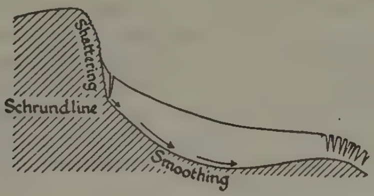


Fig. 4.

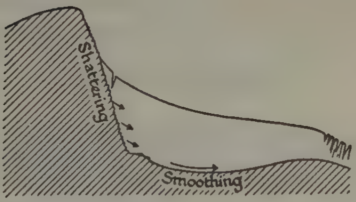


Fig. 5.

In stressing the importance of glacial sapping one must not overlook the matter of abrading and smoothing. It is here assumed that when the direction of ice movement is parallel with the rock face abrading and smoothing will predominate. For the latter is most in evidence along the floors of cirques, particularly above steps and also on the lower and gentler side and back slopes wherever these are present. Thus, as the wall at the head of a cirque retreats under the action of sapping and plucking, immediately downstream the ice abrades and smoothes. Accordingly the bulk of the material is removed by plucking, but the greater proportion of rock surface will be subsequently smoothed. It is therefore the head of the cirque that gives the real clue to the sculpturing agent.

In putting forward this hypothesis reference has been made mainly to the deepest and the best developed of the cirques visited. There are many shallower cirques whose origin might well be accounted for satisfactorily on the bergschrund hypothesis, but, on the other hand, they offer no difficulty on either explanation and therefore should not be taken as test cases. In visiting glaciated areas a constant watch was kept for the schrundline of Gilbert (2), and out of nearly fifty cirques examined only two clear instances were found. The first occurs on the slopes south-east of Llyn Llydaw, where a smoothed, moderately steep slope is surmounted by a 200- or 300-ft. precipice (Pl. VII). This scarp, however, passes into the great vertical cliffs below Y Lliwedd so that the schrundline was present only on the side wall. The break of slope also approximately coincides with the junction between the Rhyolite Tuff and the Bedded Pyroclastic Series. The second instance is that of the cliffs west of Aonach Beag, east of Ben Nevis, which surmount a long slope down to Coire Giubhsachan. The base of these cliffs is at a uniform level and they are fairly constant in height, but again they occupy the side rather than the head of a cirque. In such instances one must always allow for the possibility of a recent steepening of the cliffs by the sapping effect of winter snow patches which linger at their foot, but though such snow patches have been observed in the two examples cited above they do not seem to have done much sculpturing, as the slopes are ice-smoothed to the base of the cliffs; they are also very free from scree and are now largely vegetated.

REVERSED SLOPES.

A second major problem of cirque formation is the tendency to form reversed slopes which contain lakes after the ice has left the area. The melt-water hypothesis might well offer a partial explanation of this phenomenon. Cirque lakes generally occur near the foot of the head-wall. Melt-water pouring down this wall when excessive in quantity might well flow right under the glacier and emerge at the snout. On the other hand, when the supply is less abundant it would be expected to freeze after melting its way a certain distance under the ice. Thus the nearer one gets to the head of the cirque the more frequent would the wettings become. The back wall itself would therefore suffer the most vigorous frost action and next to this the valley floor immediately at the foot of this wall, especially as here the melt-waters pouring down the semicircumference of the cirque would converge. Thus excessive rotting of the floor would result at this point and the consequent removal of this material would still further accentuate the tendency for melt-water to collect and so the sculpturing would proceed. The removal of material would not be as easy as from the head-wall owing to the ice moving tangentially to the surface instead of tending to fall away from it, but this would probably not inhibit removal entirely.

A second factor of importance in this respect is the suggestion early made by Helland (9) and later supported by Penck (5), Davis (7), and others, that the over-deepening of the cirque floor can be attributed to glaciers which end in the cirque. This might well be true, for although it seems inadvisable to attribute the major share of cirque sculpture to glaciers in their final stage of recession, they might well be able to modify a cirque to the extent of forming a small lake basin. Also there is little doubt that a very large number of cirque lakes do not occupy true rock basins but are in a large measure due to the damming effect of moraines as witnessed by Marr (22) in his study of Lakeland Tarns. Although this might account for the majority of such lakelets, however, it does not remove the onus of accounting for the limited number of rock basins which do exist.

A third factor of much importance, and one which has long been recognized in the literature since Maxwell Close (23) put it forward nearly seventy years ago, is that glacial erosion is a maximum where the ice is thickest. This is usually intended to refer to vertical erosion accomplished largely by abrasion, and with this limitation it is probably true. Thus we have the mechanism which contrasts so vividly with river erosion, that glaciers tend to deepen any initial hollows still further.

It appears, therefore, that excessive frost action due to melt-water, heavy scouring due to maximum ice pressure, and the presence of terminal moraines combine to produce the reversed slopes and lakelets so frequently associated with cirques.

ORIENTATION OF CIRQUES.

Text-fig. 6, which is constructed after the manner of a wind rose, indicates the directions faced by forty-four well-developed cirques in the British Isles, most of which the writer has examined. The most obvious fact is that far the greater proportion of the cirques face between north-west and east-north-east. Here, no doubt, we see reflected the importance of shade in cirque development. The actual maximum lies quite definitely between north-east and east-north-east, but this might or might not have any significance, for this maximum is largely influenced by the series of cirques on the north-easterly facing slope of the Nant Ffrancon Valley, North Wales. If many more examples were taken the effect would be to smooth out any such influence of valley trend-lines and if such a maximum still persisted it would, no doubt, be related to the prevalence, temperature, and moisture content of winds from various directions during the period of cirque formation.

It thus appears that the Melt-water Hypothesis of cirque formation can account for numerous features in the morphology of British cirques which present difficulties to earlier interpretations, whether of the protectionist or erosionist schools. It also affords a more precise mechanism of sculpture but one which is not new to the physiographer. Furthermore, although this hypothesis was, in the first place, based on field evidence in the British Isles, it has since been substantially confirmed by observations made in the course of six weeks spent in cirques which are now being formed in the sides of the volcano of Snaefell, East Iceland.

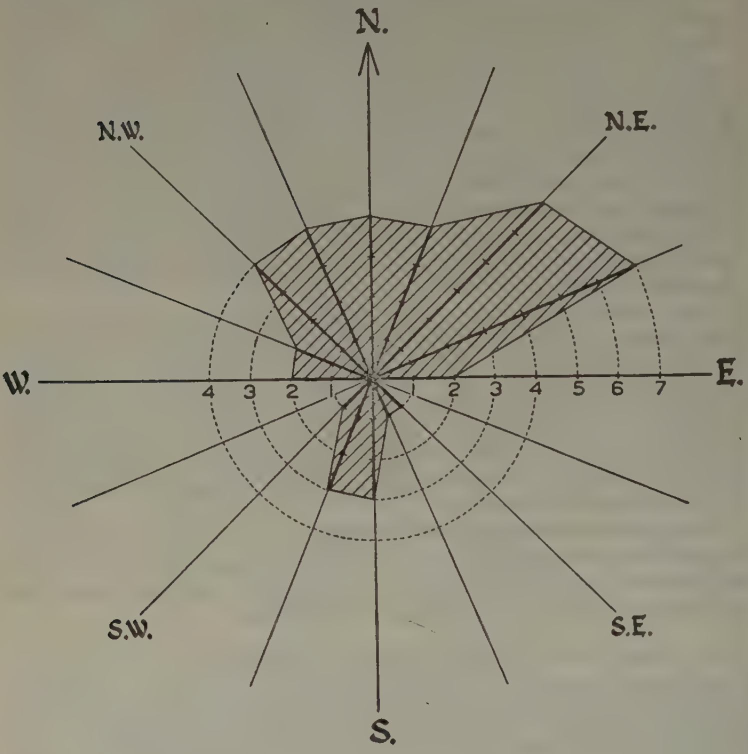


Fig. 6.

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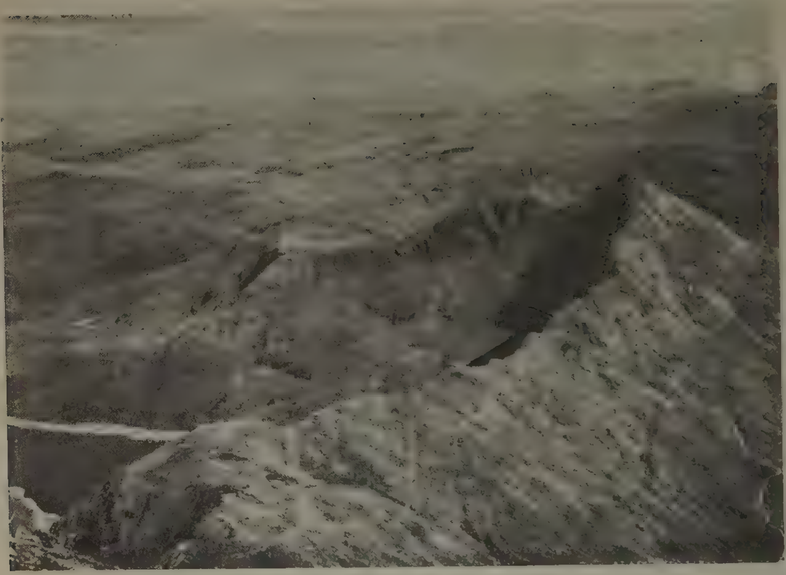

Fig. 1.—Y Lliwedd and Cwm Llydaw from the summit of Snowdon.

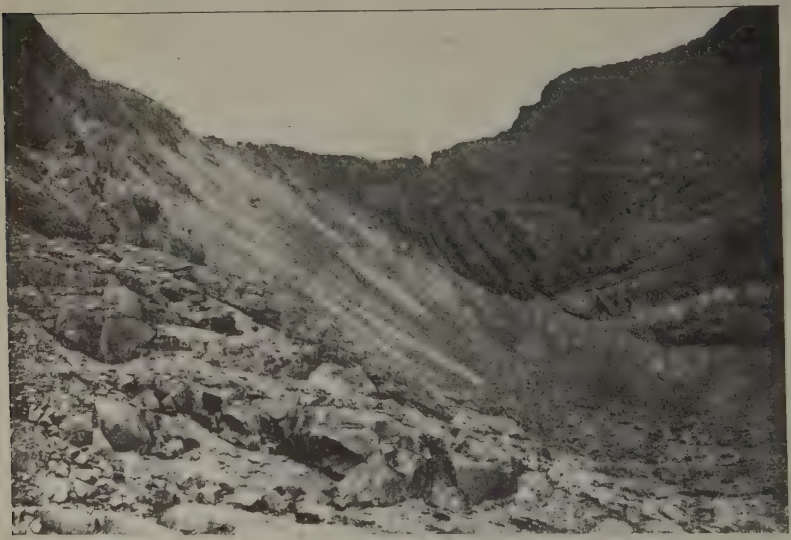

Fig. 2.—Head of Coire Lagan, Cuillin Hills.

To face p. 265.]

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EXPLANATION OF PLATE VII.

Fig.

1. Cwm Llydaw and the asymmetrical arête of Y Lliwedd, looking E.S.E. from Snowdon summit.
2. Head of Coire Lagan, showing glacial smoothing in the foreground and shattering at the foot of the head-wall.

Some British *Platycrinidae* and Descriptions of New Species.

By James Wright.

(PLATES VIII–XI.)

I. Introduction.
II. *PLATYCRINUS* Miller and *PLEUROCRINUS* Austin.
III. Some Described Species.
  (1) *Platycrinus gigas* Phillips.
  (2) ,, cf. *granulatus* Miller.
  (3) ,, *diadema* McCoy.
  (4) *Pleurocrinus coronatus* (Goldfuss).
  (5) ,, *mucronatus* (Austin).
  (6) ,, *tuberculatus* (Miller).
  (7) ,, *ellipticus* (Phillips).
IV. New Species.
  (1) *Platycrinus humilis* sp. nov.
  (2) ,, *directus* sp. nov.
  (3) ,, *balladoolensis* sp. nov.
  (4) ,, *bollandensis* sp. nov.
  (5) *Pleurocrinus grandis* sp. nov.
  (6) ,, *inurbanus* sp. nov.
  (7) ,, *coplowensis* sp. nov.
  (8) ,, *wanneri* sp. nov.

Poteriocrinidae.

  (9) *Pachylocrinus monensis* sp. nov.
  (10) *Scytalocrinus beggi* sp. nov.
V. List of Literature.
VI. Explanation of Plates.

I. Introduction.

IN this country the species which at one time or another have been assigned to the genus *Platycrinus* amount to a considerable number. From the works of J. S. Miller, J. Phillips, A. Goldfuss, T. and T. Austin, F. McCoy, de Koninck and Le Hon, etc., one might make up a list of well over a score of species, but to identify specimens from the British Carboniferous limestones with the figured or described species is a very difficult matter. This is due chiefly to the poorness of the illustrations of the species concerned or, when the figures are passably good, to the lack of prominence given to the more important characters of the calyx. Two at least of McCoy's species and one of Phillips's are not illustrated at all. There is also some confusion regarding certain species which seem to have been figured more than once under different names. In the process therefore of identifying specimens it soon becomes evident that few of the species have been placed on a satisfactory basis and that as a group the British *Platycrinidae* is much in need of revision.

A solution of all these matters is greatly to be desired, but cannot be attempted here, the main object of this paper being to illustrate and give a brief description of certain Clitheroe and Isle of Man specimens, most of which belong to the *Platycrinidae* and have been in my collection for a long time. In the course of preparing and studying these specimens some additional facts have come to light regarding a few of the described species and these are embodied in the notes which follow. The whole paper, however, can only be regarded as a preliminary effort to explore the ground and to throw a little further light on the species concerned. Opportunity is also taken to place on record two new *Poteriocrinids* from the Isle of Man.

For the loan of specimens of *Platycrinus* for study and comparison I have to thank the Keeper of the Geological Department of the British Museum and especially Mr. L. Bairstow, Assistant Keeper, who has taken much trouble in selecting certain specimens, Dr. W. E. Collinge, Keeper of the Yorkshire Museum, York, and Mr. A. G. Brighton, Curator of the Sedgwick Museum, Cambridge. My thanks are also due to Mr. D. E. Owen, Keeper of the Geological Department, Liverpool Public Museum, for information regarding the Austin Collection housed there, and Professor J. Wanner, of Bonn, Germany, for information regarding the type specimens of *P. coronatus* Goldfuss and *P. pileatus* Goldfuss. I have also to thank my friend Mr. James L. Begg, President of the Geological Society of Glasgow, for the loan of the specimen illustrated on Plate XI, Fig. 12.

II. *PLATYCRINUS* MILLER AND *PLEUROCRINUS* AUSTIN.

When, in 1821, J. S. Miller founded the genus *Platycrinus* he figured and described the following species :—

P. laevis, *P. rugosus*, *P. tuberculatus*, *P. granulatus*, *P. striatus*, and *P. pentangularis* ; the last-named, being a Blastoid, does not concern us further.

J. Phillips (1836) refigured the first four species and added *P. gigas*, *P. elongatus*, *P. ellipticus*, *P. laciniatus*, *P. contractus*, and *P. microstylus*. With the exception of the last-named species, which is not figured and like the others only described in a few words, and *P. ellipticus*, all these were apparently MS. names given by Gilbertson, whose name is appended to the species and whose collection was made use of by Phillips and contained many specimens from the Yorkshire and Lancashire areas. The figures given by Phillips are not very satisfactory ; for example those referred to *P. laevis* Miller certainly do not represent Miller's species and this is in fact questioned by Phillips himself (pl. iii, figs. 14 and 15, and p. 204).

A. Goldfuss (1838) figured and described the two English species *P. coronatus* and *P. pileatus*, the type specimens of which are said to come from near Bristol and as I am informed by Professor Wanner are now preserved in the Museum of the University of Bonn, Germany. Goldfuss apparently considered Phillips's figs. 14 and 15 already noted as probably belonging to his *P. coronatus* since he quotes *P. laevis* ? Phillips in the synonymy.

T. and T. Austin (1843–8) refigured some of Miller's and Phillips's species and added the new forms *P. antheliontes*, *P. spinosus*, *P. trigintidactylus*, and *P. mucronatus*. They, however, also claim Phillips's figs. 14 and 15, mentioned above, as belonging to their new species *P. mucronatus* and they also quote *P. laevis* Phillips in their synonymy.

In 1844 F. McCoy figured and described the Irish species *P. expansus*, *P. ornatus*, *P. punctatus*, *P. similis*, and *P. triacontadactylus*, the last named being apparently the same as the Austins' *P. trigintidactylus*. In 1849 the same author described without figures the three species *P. vesiculosus*, *P. diadema*, and *P. megastylus*.

In the Belgian work of de Koninck and Le Hon (1854) some of the above species are again figured and described along with the new forms *P. mullerianus*, *P. austinianus*, *P. olla*, *P. granosus*, and *P. arenosus*.

In 1854 McCoy repeated the descriptions of *P. vesiculosus* and *P. megastylus* already given by him in 1849 and this time gave a figure of the former species. In both descriptions of *P. megastylus* the author states that this species is excellently figured by Phillips as *P. laevis*. This reference is doubtless to Phillips's pl. iii, figs. 14 and 15, already cited, which Goldfuss thought might be his *P. coronatus* and the Austins claimed as their *P. mucronatus*. McCoy also in the 1854 work considers the Austins' *P. mucronatus* to be the same as *P. coronatus* Goldfuss.

W. H. Baily (1875, pl. 36, fig. 4) gives what he considers to be a figure of *P. coronatus* Goldfuss and quotes *P. mucronatus* Austin in the synonymy. The figure, however, cannot represent either of these species since it has a long anal tube which these species do not possess and is otherwise quite dissimilar.

It is also evident that J. Morris (1854, p. 86) and R. Etheridge (1888, p. 225) considered *P. mucronatus* Austin and possibly also *P. microstylus* Phillips to be the same as *P. coronatus* Goldfuss.

As if this confusion were not enough there are discrepancies among other species, for example *P. antheliontes* Austin. The specimens figured as this species by the Austins probably in part represent *P. pileatus* Goldfuss and *P. gigas* Phillips. (See note under the latter species further on.)

In the absence of the figured specimens, which up to the present I have been unable to see, it is a matter of the greatest difficulty to understand the discrepancies among these statements and to clear up the confusion. Discussion here therefore can only proceed on the evidence of the figures or descriptions which are sometimes not easy to follow, coupled with an examination of the rather inadequate material I have at hand. Some of the species about which I have got additional information are dealt with in the notes which follow under the different headings. Meanwhile it may be remarked that in trying to identify specimens one quickly notices certain main characteristics among the British *Platycrinidae.* On the one hand there are specimens in which the anus is on the upper surface of the tegmen and may be a simple opening, a protuberance, or even a tube. On the other, many species have the anal opening in the lateral position, just above the left and right posterior radials, with or without the interposition of plates between the radials and the opening itself. Long ago the Austins noted such characteristics and at first proposed to restrict to *Platycrinus* the species with an elongated anal tube (which they considered as the mouth), those with a simple tegmenal opening to *Centrocrinus*, and those with a lateral opening to *Pleurocrinus*, suggesting *P. mucronatus* as the type of the last named genus. For some reason or another this arrangement does not seem to have been put into use by the authors themselves since they never used the terms. In later years, however (1875), the surviving author, Fort Major Austin, appears to have somewhat modified his ideas and while still proposing to restrict to *Platycrinus* species with a "proboscidiform central tube" (*P. laevis*, etc.), he suggested another genus *Medusacrinus* for species with a lateral opening like *P. mucronatus*, *P. tuberculatus*, etc. It is not clear how he meant to group those with a simple opening in the tegmen, since they are not mentioned in the paper. Wachsmuth and Springer (1897) rejected *Centrocrinus* and *Pleurocrinus* altogether and regarded them as synonyms of *Platycrinus*, as did Bather (1900) who apparently also did not regard with favour Sollas's new genus *Brahmacrinus* for certain forms in which the lower brachials are incorporated in the calyx (*Quart. Journ. Geol. Soc.*, lvi, 1900, 271). Incidentally, Sollas uses the term *Pleurocrinus* (*Platycrinus*) *rugosus* in referring to this species and one gathers from his remarks that he considered *Pleurocrinus* as a distinct genus though closely allied to *Platycrinus.* Professor Wanner (1916) in describing the Permian crinoids of Timor has revived with some emendations the Austins' name *Pleurocrinus* for certain species of *Platycrinidae* which among other characters have the anal opening in the lateral position. I am not aware that any specimens comparable with Wanner's *Neoplatycrinus* occur in British rocks. In this genus the anus is also in the lateral position but the tegmen consists for the most part only of five large orals and few supplementary plates. This is in contrast to the majority of British Carboniferous species in which the tegmen is composed of many plates. There are, however, as was contended by the Austins—although the plan here suggested is not quite the same—a number of British species which can be referred to *Pleurocrinus*, since in practice it is possible to group certain of the forms under this genus while restricting to *Platycrinus* the species in which the anus opens out on the tegmenal surface either as a simple opening, a protuberance or a tube. In American species the arms are often found attached to the calyx and the structure of the tegmen and the position of the anal opening are seldom observed. This was one of the reasons given by Wachsmuth and Springer for the rejection of *Pleurocrinus*. (A tube, however, has been seen in two species, viz. *P. excavatus* Hall and *P. burlingtonensis* O. & Sh., but it does not seem to have attained the length shown by such British species as *P. laevis* Miller and *P. trigintidactylus* Austin. *P. gigas* Phillips is another British species which has a rather prominent tube, but its existence in this species was only discovered last year.) On the other hand, among British species, particularly those occurring in massive or knoll limestone, it is rare to find any with the arms in position. Most specimens in fact are broken or injured at the arm bases, only an odd primibrach and secundibrach being occasionally found attached to the calyx, and so in the determination and classification of the different forms we have to rely chiefly on the general shape of the calyx, the ornamentation if any (and this seems to be somewhat variable in one and the same species), and above all on the position of the anal opening. As a result, therefore, of the present examination, the following grouping which is based on the position of the anal opening has suggested itself, but its special application is to the British species under consideration and it is put forward tentatively. The various groups mentioned are exemplified in the species illustrated on the plates accompanying this paper.

PLATYCRINUS.

(1) *Platycrinus laevis* group.

Species like *P. laevis* Miller, *P. gigas* Phillips, *P. trigintidactylus* Austin, and *P. spinosus* Austin, in which the anal opening is at the end of a tube, a contraction of, or " bottle-neck " on the tegmen. In the posterior inter-radius the middle plate resting on the shoulders of the left and right posterior radials is usually large and may be about twice the length and breadth of the iR occupying the same position in the other inter-radii, cf. Pl. IX, Figs. 2, 5, and 8. The Belgian species *P. mullerianus* de Kon. & Le Hon, and *P. austinianus* de Kon. & Le Hon belong to this group as apparently also the American species *P. excavatus* Hall and *P. burlingtonensis* O. & Sh.

(2) *Platycrinus bollandensis* group.

Species like *P. bollandensis* sp. nov., *P. diadema* McCoy, *P. conglobatus* J. Wright, *P. crassiconus* J. Wright, *P. humilis* sp. nov., *P. directus* sp. nov., *P. balladoolensis* sp. nov., and probably *P. granulatus* Miller, in which the anus is a simple opening, sometimes more or less protuberant, on the upper surface of the tegmen. In the posterior inter-radius the middle plate resting on the shoulders of left and right posterior radials is usually hexagonal in shape but although it may be slightly smaller or larger does not differ greatly in size from the corresponding iR of the other inter-radii. It is surmounted by other plates variable in number which intervene between it and the anal opening. When looked at from above the anal opening is always visible in its entirety on the tegmenal surface; cf. Pl. X, Figs. 9–16; Pl. XI, Figs. 2, 4, 5, 8, 10, and 13. Most American species in which the tegmen is visible seem to belong to this group, also the Permian (Timor) species *P. wachsmuthi* Wanner.

PLEUROCRINUS.

(1) *Pleurocrinus coronatus* group.

Species like *Platycrinus coronatus* Goldfuss, *Platycrinus megastylus* McCoy, *Pleurocrinus grandis* sp. nov., *P. inurbanus* sp. nov., *P. grandis* sp. nov., probably also *Platycrinus rugosus* Miller, which have the anus in a lateral position, the opening itself being separated from posterior radials by a small iR, usually pentagonal, the upper part truncated, the lower part resting on the shoulders of left and right post. RR. This post. iR as a general rule is small compared with the middle iR of the other inter-radii, the anus opening directly above it; or it may occasionally be surmounted by two or more very small plates which intervene between it and the opening, cf. Pl. VIII, Fig. 1; Pl. IX, Fig. 4; Pl. X, Fig. 5. The following American species appear to be referable to this group: *Platycrinus eminulus* Hall, *P. pileiformis* Hall, *P. quinquenodus* White, and *P. halli* O. & Sh.; also the Permian (Timor) species *Pleurocrinus globosus* Wann. and *P. depressus* Wann.

(2) *Pleurocrinus coplowensis* group.

Species like *Pleurocrinus coplowensis* sp. nov., *P. wanneri* sp. nov., *Platycrinus tuberculatus* Miller, and *P. ellipticus* Phillips, in which the anus is also in the lateral position, the opening itself being directly above the post. RR with no intercalated plates. In the British species of this and the previous group the anal opening is rarely visible, even partly, when viewed from above; but in the Permian (Timor) species it may be wholly or partly so, cf. Pl. IX, Fig. 11; Pl. X, Figs. 1, 17, and 21. None of the American species seem to be assignable to this group, but the Belgian species *Platycrinus granosus* de Kon. & Le Hon appears to be referable to it as also the Permian (Timor) species *Pleurocrinus spectabilis* Wann., *P. pusillus* Wann., and *P. goldfussi* Wann.

How far the classification here given will hold good for species not yet examined only time and further work will show. A scheme comprehensive enough to embrace all the British species, let alone the foreign ones, together with a fresh diagnosis of both *Platycrinus* and *Pleurocrinus* cannot be attempted at this stage, but in the case of the British species here enumerated, while it is admittedly very difficult to frame a brief and precise formula for each group, there is in practice no difficulty whatever in separating the species of one group from the other. Thus under *Pleurocrinus*, species like *P. coplowensis* sp. nov., *P. wanneri* sp. nov., *P. ellipticus* Phillips, with the simple anal opening directly above the posterior radials naturally fall into one group and species like *P. coronatus* Goldfuss, *P. grandis* sp. nov., *P. inurbanus* sp. nov., etc., into another. All these are so distinct from the typical *Platycrinus* that one can have little hesitation in assigning them to *Pleurocrinus*. On the other hand there is at least one species which has given some trouble and is more difficult to classify, viz. *Platycrinus pileatus* Goldfuss. I have several specimens from Bellman Quarry, Clitheroe, which from their general characters I think belong to this species but none show the anal opening satisfactorily. Professor Wanner informs me that the type specimen, now in the Museum of the University of Bonn, has a small iR about half the size of the middle iR of the other inter-radii, just below the anal opening, in this respect not unlike some species of the *Pleurocrinus coronatus* group. The anal opening is visible in its entirety on the tegmenal surface. From its general habitus, etc., Professor Wanner thinks this species is more a *Platycrinus* than a *Pleurocrinus* and he would place it in the *Platycrinus bollandensis* group. Judging from the figures of *P. pileatus* given by Goldfuss and by de Koninck and Le Hon I am inclined to agree. At the same time it seems evident that this species, and possibly others, are very closely linked both to *Platycrinus* and *Pleurocrinus* in the anal characters as here noted and so do not quite fit into the present grouping. It may be that another group will have to be formulated for the reception of such forms, but this problem cannot be solved until a larger series of specimens has been examined.

III. SOME DESCRIBED SPECIES.

(1) *Platycrinus gigas* Phillips.

Pl. IX, Figs. 2, 5, and 8.

Platycrinus gigas Gilb., Phillips, 1836, p. 204, pl. iii, figs. 22, 23.
Platycrinus gigas Phillips, Austin, 1843–8, p. 38, pl. 4, fig. i.
Platycrinus gigas Phillips, McCoy, 1844, p. 175.

Specimens which I have always considered to belong to *P. gigas* Phillips are frequently met with at Coplow Knoll, Clitheroe; in fact in my experience this is one of the most abundant species among the *Platycrinidae* to be found there. So far I have collected over ninety specimens ranging from young individuals measuring less than 9 mm. across the radials of dorsal cup to large mature specimens over 37 mm. in diameter of cup. This species is not likely to be confused with any other since it has some well-marked characteristics. It is distinguished by the smooth plates and somewhat rounded nature of the dorsal cup and particularly by a rather high tegmen the plates of which, when not worn, often show a single blunted tubercle. The tegmen itself has a pronounced " bottle neck " where it contracts and is prolonged into a tube at the extremity of which it is encircled by spiniferous plates. The anal opening is at the end of this tube. Phillips's figure of the species (pl. iii, fig. 22) does not show the tube or any anal opening whatsoever—a common failing of Phillips's drawings—but there can be no doubt that it is drawn from such a specimen as that shown on our Pl. IX, Fig. 5. As a matter of fact, in nearly every specimen found in the knolls the tube is broken away at the contraction of the tegmen as shown in our Pl. IX, Figs. 2 and 5. Although he evidently paid little attention to the anal opening, Phillips's figure is clearly a posterior view. It shows the large hexagonal inter-radial plate characteristic of this species in the posterior inter-radius. This plate is usually about twice the size of the corresponding inter-radial of the other inter-radii. Comparing the specimen of our Pl. IX, Figs. 2 and 5, and others like it with Phillips's figure there seems little doubt at all that our identification with *P. gigas* is correct. In the posterior view of our Pl. IX, Fig. 5, the large hexagonal inter-radial resting on the left and right posterior radials is surmounted by two smaller plates forming in most specimens the rim of the anal opening since it is at this position that the proximal tube plates are usually broken away. In Pl. IX, Fig. 2, the specimen is viewed from the right antero-lateral inter-radius and shows the contraction of the tegmen to the left or posterior side where it merges into the tube. Fig. 8 on the same plate is a view of a flattened specimen which shows the tube in position. This figure should be compared with Fig. 2 since both are nearly from the same viewpoint. Although I have occasionally met with detached portions of tube and have long suspected that *P. gigas* had such a structure, the flattened specimen here illustrated and a smaller one are the only two I have so far found which show the complete tube in position. The spiniferous plates at the distal end of tube are somewhat broken in Fig. 8, but two are still intact and may be observed on the right of photograph. The Austins figure what they consider to be this species in their *Monograph,* pl. 4, fig. 1*a–c,* but their drawing of the tegmen on fig. 1*b* certainly does not represent *P. gigas* and if correctly drawn belongs to another species altogether. In the drawings of their proposed new species *P. antheliontes* (pl. 2, figs. 3*k–r*) they seem to have mixed up two or more calices. As already observed their figs. 3*k* and *l* probably represent *P. pileatus* Goldfuss, and I suspect that fig. 3*m* of this plate is just a side view of a young specimen of *P. gigas* which can be perfectly matched with young individuals of this species from Coplow. In the possession of a tube *P. gigas* is closely related to *P. laevis* Miller, *P. trigintidactylus* Austin, and the Belgian species *P. mullerianus* de Kon. & Le Hon and *P. austininuas* de Kon. & Le Hon, but adequate comparison between these species is not possible at this stage.

After this was written I received four specimens from the British Museum (Gilbertson Collection) Nos. E26289, E26290, E26292, and E26293, labelled, correctly I think, *P. gigas* Phillips. One of these, E26289, is a very large specimen measuring about 2⅛ inches (approx. 54 mm.) in height, and about 1¾ inches (approx. 44·4 mm.) across the radials of the cup and such a specimen as this well justifies the specific name. The tube, however, is broken away at the usual position as is also the case in the other three specimens which are much smaller. All these are similar to the Coplow specimens noted above and confirm the identification of the species. It may further be added that Mr. Bairstow informs me that the specimen in the Gilbertson Collection in the British Museum figured by Phillips as *P. gigas*, which I have not seen, has the anal opening in the usual position, but the tube is broken away in a similar manner to the other specimens mentioned above.

(2) *Platycrinus* cf. *granulatus* Miller.
Pl. X, Figs. 13–16.

Platycrinus granulatus Miller, 1821, p. 82, pl. opposite p. 81.
Platycrinus granulatus Miller, Phillips, 1836, p. 204, pl. iii, fig. 16.
Platycrinus granulatus Miller, Austin, 1843–8, p. 33, pl. 3, fig. 2.
Platycrinus granulatus Miller, de Koninck and Le Hon, 1854, p. 179, pl. vi, fig. 5.

The specimen illustrated is a typical *Platycrinus* and although differing somewhat in detail, apparently comes near to *P. granulatus* Miller. This species, however, like many of the others, is difficult to identify with confidence. Phillips gives a figure (pl. iii, fig. 16) showing the complete calyx with no indication of the anal opening. The Austins also give several figures (pl. 3, figs. 2*j*–*o*) including a cup and an outline of the calyx, but the tegmen here shows a protuberance and is different from that given by Phillips. De Koninck and Le Hon also give two figures, a bottom and a side view of a dorsal cup (pl. vi, figs. 5*a* and *b*). So far, the figures all agree in the fact that the plates of the dorsal cup are studded with granules. In the Austins' figures, and possibly also in Miller's (plate opposite p. 81), the granules are rather finer and not so closely packed as in the figures of Phillips and de Koninck and Le Hon. The specimen from Clitheroe shown on our Pl. X, Figs. 13–16, comes nearer to Phillips's figure than to any of the others. The anus here is a simple opening on the tegmenal surface but the specimen is somewhat worn and it may originally have been slightly protuberant. This specimen, however, does not quite agree with eight specimens which I have had on loan from the British Museum (Gilbertson Collection) Nos. E26266, E26269, E26271–6. They are all labelled *P. granulatus* Miller, and were presumably so regarded by Gilbertson or Phillips himself, but I was surprised to find that they are a mixed lot and belong to three if not four different species. In E26266, E26273–5, which may I think be taken as the most typical of the species, the cup and tegmen are about the same height, the basal circlet is flat and the plates of the cup are studded with prominent granules, more pronounced in this respect than in the Clitheroe specimen of our Pl. X, Figs. 13–16. The anus in these specimens also seems to have been more protuberant since it is clearly broken away at the proximal end on the three largest specimens, E26273–5, but is well shown on the smallest specimen, E26266, where it is intact and forms a conspicuous elevation on the tegmen.

Although at first sight somewhat similar, E26271, E26272, and E26276 belong to two distinct and probably undescribed species. Among other differences the anal opening is lower in the inter-radius, not visible entirely from above, and the small truncated iR resting on the post. radials indicate that all three belong to the *Pleurocrinus coronatus* group. In E26271 and E26276, however, the cup is more rounded and the column facet is encircled by a prominent rim which none of the other specimens here noted possess. The granular ornamentation is also finer and not so closely arranged. In E26272 the cup is much more elongated than in any of the others and this specimen belongs to another species.

The remaining specimen, E26269, is much larger but is somewhat damaged as to the dorsal cup. It clearly belongs to another species altogether. The tegmen is very flat and although difficult to see as to details the anus is low down in the lateral position and this specimen also probably comes into the *Pleurocrinus coronatus* group. From what can be seen of the cup plates the ornamentation is different from any of the others. Altogether this specimen has some resemblance to *P. inurbanus* sp. nov. described further on but it is probably better placed under *P. rugosus* at present.

So far as can be gathered from the above specimens and the figures the main features of *Platycrinus granulatus* would appear to be a granularly studded cup with rather flat basal circlet, a tegmen nearly of the same height as cup, moderately rounded and composed of numerous plates, the anal opening on the surface as a protuberance. Before we can arrive at a precise definition of this species, however, it is evident that many more specimens must be examined. The Clitheroe specimen illustrated on Pl. X, Figs. 13–16, differs from the British Museum specimens here regarded as *P. granulatus* in the rather straight sides of the cup, a somewhat higher tegmen, and also in the less pronounced degree of the granular ornamentation on the cup plates. It is, therefore, here meantime referred to *Platycrinus* cf. *granulatus* Miller.

(3) *Platycrinus diadema* McCoy.

Pl. XI, Figs. 1, 2, 4–10.

Platycrinus diadema McCoy, 1849, p. 426.
Platycrinus diadema McCoy, 1854, p. 108.

This species has not to my knowledge been illustrated before. It was described by McCoy in 1849, and the description reprinted in the same author's *Contributions to British Palaeontology*, 1854,

108. Both descriptions are given without figures but there seems no doubt about the identity of the specimens now illustrated. I have collected several specimens from Bellman Quarry, Clitheroe, which although somewhat smaller agree in character with other specimens under this name in the Sedgwick Museum, Cambridge. The latter come from Cleenish, Co. Fermanagh, Ireland, and are probably the specimens mentioned in McCoy's description since this is the locality given by him. Of the species he says, "The very wide depressed turban-like form of the species (which I find constant) easily distinguishes it from its congeners. All the plates are smooth." This and the description as a whole confirms the identity of the species. The Bellman specimens are in some cases much better preserved than those from Ireland particularly as to the dorsal cup. In McCoy's description it is stated "columnar adherence circular, crenulated, one-third the diameter of pelvis but seated at the bottom of a deep circular excavation three-fourths the diameter of pelvis". The character of this part of the basal circlet is specially well shown in some Bellman specimens, e.g. Pl. XI, Fig. 7, but the somewhat peculiar aspect here is not emphasized by McCoy. The column facet is certainly at the bottom of a depression, but is perhaps better described as being surrounded by a wall or rampart which is not circular but when the specimen is slightly tilted to the left is in the form of a Gothic arch. This character is constant in all the specimens I have seen and although not so conspicuous in worn examples is usually noticeable (cf. Pl. XI, Figs. 1, 6, and 7). This appears to be one of the main characters of the species. The depressed and rather wide spreading calyx is also characteristic and somewhat unique among British species (Pl. XI, Figs. 2, 5, and 9). The species sometimes attains a large size as may be noted from Pl. XI, Fig. 8, which is a posterior view of a specimen from Bolland in the York Museum. This specimen and one from the Sedgwick Museum (regd. No. E5695) shown on the same plate, Figs. 1, 4, and 5, are somewhat broken at the arm bases, but Figs. 2 and 9 on this plate are side views of a rather smaller but more complete specimen from Bellman Quarry and these give a better idea of the spreading calyx.

(4) *Pleurocrinus coronatus* (Goldfuss).

Pl. X, Figs. 5–8.

Platycrinus coronatus Goldfuss, 1838, p. 344, pl. xxxi, figs. 8*a* and *b*.

Specimens belonging to this species occur at Bellman Quarry Clitheroe, and seem to differ little from the type (Goldfuss, 1838 pl. xxxi, figs. 8*a* and *b*). I am figuring two specimens. In the posterio view on Pl. X, Fig. 5, the basal circlet is missing but the anterio view on Fig. 8 shows the outline of the basal circlet in anothe specimen and gives a better idea of the shape of the calyx as whole. In the posterior view on Fig. 5 the position of the ana opening is well seen but it is interesting to note that the aperture itself, while always lateral, seems to be somewhat variable as to its exact position between the ambulacrals, i.e. it is not always situated midway between them. Thus in the specimen illustrated the anal opening is rather to the right of the middle line. This variability is also seen in another species, e.g. *P. inurbanus* sp. nov. (Pl. IX, Fig. 4), where in this case the opening is in the reverse direction.

(5) *Pleurocrinus mucronatus* (Austin).

Platycrinus mucronatus Austin, 1843–8, p. 23, pl. 2, fig. 1; pl. 5, fig. 2.

So far I have been unable to get much satisfactory information about this species which was suggested by the Austins as the type of their proposed new genus *Pleurocrinus*. I am informed by Mr. D. E. Owen, Keeper of the Geological Department of the Liverpool Museum, that no specimens bearing this name are in the Austin Collection in that institution. The Austins state (*Monograph*, Explanation of Plates, p. ii), that the specimens from which their figures of *P. mucronatus* on pl. 2 were drawn are in the collection of the Bristol Literary and Philosophical Institution and possibly are still there. I have not seen them. In any case, judging from the figures, the specimens seem to be rather poorly preserved and none of them show the anal opening satisfactorily. Also the outline of the dorsal cup on pl. 2, fig. 1*b*, does not quite agree with the side view of the calyx given on pl. 5, fig. 2*a*. The latter is stated by the Austins to be drawn from a specimen in the Gilbertson Collection. This figure appears to me to be just an anterior view of *P. coronatus* Goldfuss and is remarkably similar to the specimen shown on our Pl. X, Fig. 8, which is referred to this species. As already mentioned McCoy and others regarded *P. mucronatus* as a synonym of *P. coronatus* and there thus seems to be a good deal of justification for this view. As regards Phillips's figs. 14 and 15 of *P. laevis* which were thought by Goldfuss and claimed by the Austins and McCoy to belong to their respective species, *P. coronatus*, *P. mucronatus*, and *P. megastylus*, the balance of the evidence seems to be in favour of McCoy. None of the Austins' figures come near to Phillips's unless we are to regard the very small specimens on pl. 5, figs. 2*b*, *c*, and *d*, claimed by the Austins to be the young of *P. mucronatus*. On the other hand I should hazard the opinion that these small specimens are young examples of McCoy's *P. megastylus*. This species was never figured, but from McCoy's description and an examination of certain specimens from Knoll Wood, Newton in Bolland, the species is quite recognizable and different from any of the others. Its special character, as emphasized by McCoy, is the somewhat large column facet encircled by a prominent rim. To that may be added a more rounded dorsal cup and a tegmen of few plates each of which is prolonged into a sharp thorn-like spine. The anal opening is similar to that in *P. coronatus* and this may account for Goldfuss and the Austins thinking that Phillips's figs. 14 and 15 represented their species. It has to be admitted that Phillips's figures are not very good, but they are plainly intended to show the prominent column facet with encircling ring characteristic of *P. megastylus* but not possessed by *P. coronatus* or *P. mucronatus*.

Six specimens in the British Museum (Gilbertson Coll.), Nos. E284, E26296–8, E26299, E26300 are labelled *P. mucronatus* Austin. This is a mistake. E284, E26296–8, E26300 are rather broken examples of *P. diadema* McCoy or a very closely related species. They are all smaller than the specimens of *P. diadema* illustrated on Pl. XI, Figs. 1, 2, 4–10. The calyx is perhaps not quite so spreading but in all essential characters they are similar. I have also several specimens like these from Knoll Wood, Newton in Bolland. The fifth specimen, E26299, belongs I think to *P. megastylus* McCoy, and has all the characters of that species noted above. It is hoped to illustrate and deal further with this species at another time. Meantime so far as *P. mucronatus* Austin is concerned it evidently must be regarded as a synonym of *P. coronatus*. At any rate it cannot be added to our lists with any confidence.

(6) *Pleurocrinus tuberculatus* (Miller).

Pl. X, Figs. 1–4.

Platycrinus tuberculatus Miller, 1821, p. 81 and pl. opposite.
Platycrinus tuberculatus Miller, Phillips, 1836, p. 204, pl. iii, fig. 17.
Platycrinus tuberculatus Miller, Austin, 1843–8, p. 41, pl. 4, fig. 3.
Platycrinus tuberculatus Miller, de Koninck and Le Hon, 1854, p. 184, pl. vi, figs. 7 and 8.

I am illustrating four views of a specimen from Knoll Wood, Newton in Bolland, Yorkshire, which is I think a typical example of *P. tuberculatus*. Miller's original figures (plate opposite p. 81), only show a side view of a dorsal cup and a basal circlet. Phillips (pl. iii, fig. 17) figures a complete calyx showing the tegmen, but the position of the specimen is not indicated and no anal opening is seen. The Austins (pl. 4, fig. 3*m*) give a figure of the calyx from the posterior with anal opening in the lateral position, but the opening itself is separated from the left and right shoulders of the posterior radials by a fairly large plate. In general characters it agrees fairly well with Phillips's figure. De Koninck and Le Hon (pl. vi, fig. 7*a*–*c*) also figure the species, but give no posterior view and their outline of the calyx is somewhat different. Their figure of the tegmen, however (fig. 7*c*), shows no anal opening on its surface and therefore it is presumed that the anus in this specimen is also in the lateral position. Although as a whole the figures noted leave much to be desired there seems little doubt they are all intended to represent the same form. It is clear that the anal opening in this species is situated in the lateral position but in the specimen now illustrated on our Pl. X, Figs. 1–4, there are no plates interposed between the anal opening and the corners of the left and right posterior radials as shown in the Austins' figure. The latter, however, may be an individual variation or an error in drawing. Other specimens I have seen lead me to conclude that the anus in this species opens directly above the post. radials with no intervening plates as shown in the Knoll Wood specimen here illustrated.

(7) *Pleurocrinus ellipticus* (Phillips).

Pl. X, Figs. 21–4.

Platycrinus ellipticus Phillips, 1836, p. 204, pl. iii, figs. 19, 21.

Specimens referable to this species occur at Coplow Knoll, Clitheroe, and one of these is illustrated on Pl. X, Figs. 21–4. This specimen agrees well with Phillips's figure of *Platycrinus ellipticus* (pl. iii, fig. 19) in so far as that figure only shows a side view, probably the anterior, of the calyx. Although slightly worn the ornament on my specimen also agrees well. In the Clitheroe specimen the anal opening is well shown in the lateral position and there are no plates between the opening and the posterior radials. The species therefore is a typical *Pleurocrinus*. Five specimens from Yorkshire belonging to the Gilbertson Collection in the British Museum, E26280–1, E21301–3, are labelled *Platycrinus ellipticus* Phillips but they have no resemblance whatever to the present form. Although somewhat larger, all five are very similar to the Knoll Wood specimen illustrated under *Pleurocrinus tuberculatus* (Miller) on Pl. X, Figs. 1–4, and if we are to place any reliance on Phillips's figures at all I think there is no doubt they belong to this species and not to *P. ellipticus*.

IV. NEW SPECIES.

(1) *Platycrinus humilis* sp. nov.

Pl. X, Figs. 9–12.

Diagnosis.—A small species; dorsal cup elongated with rather pointed conical basal circlet; tegmen very low in relation to cup and composed of many plates; anus as simple opening on surface of tegmen; interambulacral areas on tegmen sunken in relation to ambulacrals.

Holotype.—J. Wright Coll. No. 2334.

Locality.—Knoll Wood, Newton in Bolland, Yorkshire.

Horizon.—C_2 (Parkinson, 1936).

Dimensions of Holotype.—Height of calyx over all, 20·5 mm.; height of dorsal cup, 15·8 mm.; height of tegmen, 4·9 mm.; greatest width of cup across RR, 22 mm.

Remarks.—Only one specimen of this species has so far been found. It comes near to the Scottish species *P. crassiconus* in that the plates are smooth but it has an even more elongated cup and relatively lower tegmen. The low nature of the tegmen with the sunken interambulacral areas give this species a characteristic aspect not to be confounded with any of the other species here dealt with.

(2) *Platycrinus directus* sp. nov.

Pl. IX, Figs. 7 and 9.

Diagnosis.—A moderate sized species; calyx wider than high; dorsal cup gently rounded, basal circlet rather flat; tegmen about half as high as cup, very flat or straight on top; plates of cup and tegmen ornamented with small pustules; anal opening on surface of tegmen.

Holotype.—J. Wright Coll. No. 2329.

Locality.—Dolomitized limestone, shore at Balladoole, Isle of Man.

Horizon.—D_2 (Lewis, 1930).

Dimensions of Holotype.—Height of calyx over all, 21·4 mm.; height of dorsal cup, 14 mm.; greatest width of cup across RR, 30 mm.

Remarks.—This species is represented by two specimens, the smaller of which is taken as the holotype. The other specimen is somewhat larger but is not quite so well preserved. The chief characters of this species are the very flat and somewhat low nature of the tegmen, the rather broad and gently rounded cup and the uniformly pustular ornamentation of the plates of cup and tegmen. The plates of this species are also rather thin as compared with the other Isle of Man species.

(3) *Platycrinus balladoolensis* sp. nov.

Pl. IX, Figs. 10 and 12.

Diagnosis.—A moderate sized species; dorsal cup sub-conical, somewhat expanding; tegmen about the same height as cup or a little higher; cup plates with tubercular ornamentation radiating in lines from column facet to sutures of basals and converging on radials towards radial facets; tegmenal plates swollen, each plate having the form of a blunted spine, inter-radial plates with a single tubercle near their upper margins.

Holotype.—J. Wright Coll. No. 2331.

Locality.—Dolomitized limestone, shore at Balladoole, Isle of Man.

Horizon.—D_2 (Lewis, 1930).

Dimensions of Holotype.—Height of calyx over all, 30·5 mm.; height of dorsal cup, 15·5 mm.; width of dorsal cup across RR, 33·3 mm.

Remarks.—This species is represented by one specimen and is distinguished from the other Isle of Man species here dealt with by the more expanding cup and the thick and somewhat bluntly spiniferous nature of the tegmenal plates. The posterior side of the holotype is rather weathered but is sufficiently preserved to indicate the position of the anus which opens out on the tegmenal surface as in *P. diadema*, etc. The species, therefore, is a typical *Platycrinus*.

(4) *Platycrinus bollandensis* sp. nov.

Pl. XI, Figs. 11 and 13.

Diagnosis.—Calyx of medium size; dorsal cup expanding from outer margins of basal circlet which is rather flat in region of column facet; tegmen about the same height as cup; cup plates with tubercular ornamentation; tegmenal plates swollen, tubercular; iR plates occasionally with a single tubercle in their centres; anal opening on tegmenal surface.

Holotype.—In Yorkshire Museum, York (Pl. XI, Figs. 11 and 13).

Paratype.—In Yorkshire Museum, York.

Locality.—" Bolland."

Dimensions of Holotype.—Height of calyx over all, 29 mm.; height of dorsal cup, 14·5 mm.; width of dorsal cup across RR, 25 mm.

Remarks.—This species is represented in the York Museum by two specimens. One of these is labelled *P. rugosus* Miller the other *P. gigas* Phillips. After cleaning and exposing the anal opening it was found that both specimens belong to the same species but clearly not to either of the two mentioned. I cannot trace a British species which exactly agrees with these two specimens and therefore I conclude that they belong to an undescribed form. The general character of the calyx and the position of the anal opening are illustrated on Pl. XI, Figs. 11 and 13, and it is evident that the species is a typical *Platycrinus*. In both specimens the middle iR plates are nearly all equal in size. In the holotype, however, the left anterior middle iR is somewhat larger than the others.

(5) *Pleurocrinus grandis* sp. nov.

Pl. VIII, Figs. 1–7.

Diagnosis.—A large species; calyx about as high as wide; dorsal cup much swollen, slightly constricted towards top of RR; basal circlet slightly rounded; tegmen moderately high but rather flat on top; surface of plates nearly smooth or with fine shagreen-like ornament and on dorsal cup dotted with irregularly disposed tubercles; tegmenal plates thick, generally culminating in a single pointed tubercle in their centres; anal opening in lateral position, separated from post. RR by a comparatively small plate, pentagonal in shape, the upper part truncated, the lower part resting equally on the shoulders of left and right posterior radials.

Holotype.—J. Wright Coll. No. 2325.

Paratypes.—J. Wright Coll. Nos. 2326–8.

Locality.—Balladoole, in tideway, Isle of Man.

Horizon.—D_2 (Lewis, 1930).

Dimensions of Holotype.—Height of calyx over all, 55 mm., approx. $2\frac{3}{16}$ inches; height of dorsal cup, 34·4 mm., approx. $1\frac{3}{8}$ inches; greatest width of dorsal cup, post. to ant., 55 mm., approx. $2\frac{3}{16}$ inches.

Remarks.—This species attains a large size and may be coupled with *Platycrinus gigas* Phillips as one of the giants among British *Platycrinidae.* It of course differs from *P. gigas* in the form of the tegmen and particularly in the position of the anal opening which is typically of the *Pleurocrinus coronatus* group. The holotype, however, large as it is, is exceeded in size by another specimen No. 2326 from the same locality, but it is not quite so well preserved. Another two specimens Nos. 2327 and 2328 are much smaller, but show all the characters of the larger specimens. These are illustrated on Pl. VIII, Figs. 3, 4, and 5. The holotype shown on the same plate, figs. 1, 2, 6, and 7, was recorded as *Platycrinus gigas* Phillips in John Smith's paper on the Isle of Man (Smith, 1911, p. 152), but this was a mistake (Wright, 1935, p. 210). So far I have not seen any specimens from the Isle of Man which could be referred to *P. gigas*. Among British forms we may I think regard the present species as the largest of the *Pleurocrinus coronatus* group and *Platycrinus gigas* as the largest of the *Platycrinus laevis* group.

(6) *Pleurocrinus inurbanus* sp. nov.

Pl. IX, Figs. 1, 3, 4, and 6.

Diagnosis.—A moderate sized species ; calyx higher than wide ; tegmen about the same height as cup or somewhat higher ; cup plates coarse, ridged, the ridges on radials nearly parallel to sutures ; basal circlet rather flat with ridges both parallel and at right angles to sutures ; tegmenal plates also coarse with fine shagreen-like ornament on smoother parts ; anus lateral, separated from post. RR by a small iR resting on shoulders of left and right post. RR and supporting two smaller plates which intervene between it and the anal opening.

Holotype.—J. Wright Coll. No. 2319.

Paratypes.—J. Wright Coll. Nos. 2318, 2320, 2324.

Locality.—Coplow Knoll, Clitheroe.

Horizon.—C_1 (Parkinson, 1936).

Dimensions of Holotype.—Height of calyx over all, 36 mm. ; height of dorsal cup, 16 mm. ; greatest width of cup across RR, 35 mm.

Remarks.—Seven specimens from Coplow Knoll are referred to this species which appears to be different from any other hitherto figured. For some time, however, I felt inclined to think that all these specimens might belong to *Platycrinus rugosus* Miller, but this does not seem likely. A reference to the figures of Miller (plate opposite p. 79), indicates that more than one species is represented in the drawings and beyond the fact that the cup plates are apparently thick and distinguished by varying degrees of ornament one gets no clear conception of the species they are intended to portray. No outline of the complete calyx is given although one surmises from the remarks of the author that he had a specimen or specimens

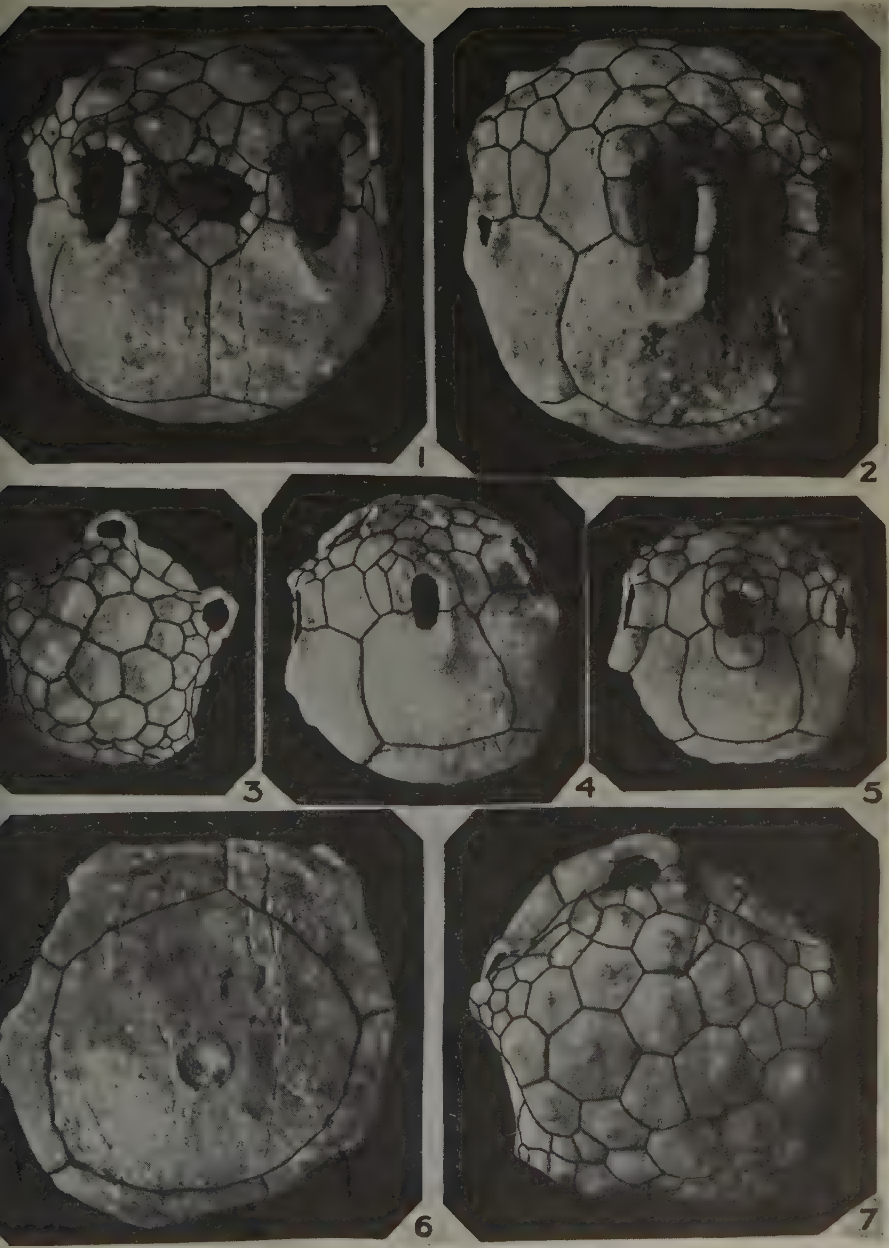

Photo J. Wright.

PLEUROCRINUS GRANDIS sp. nov. FROM THE ISLE OF MAN.

[*To face p.* 282.

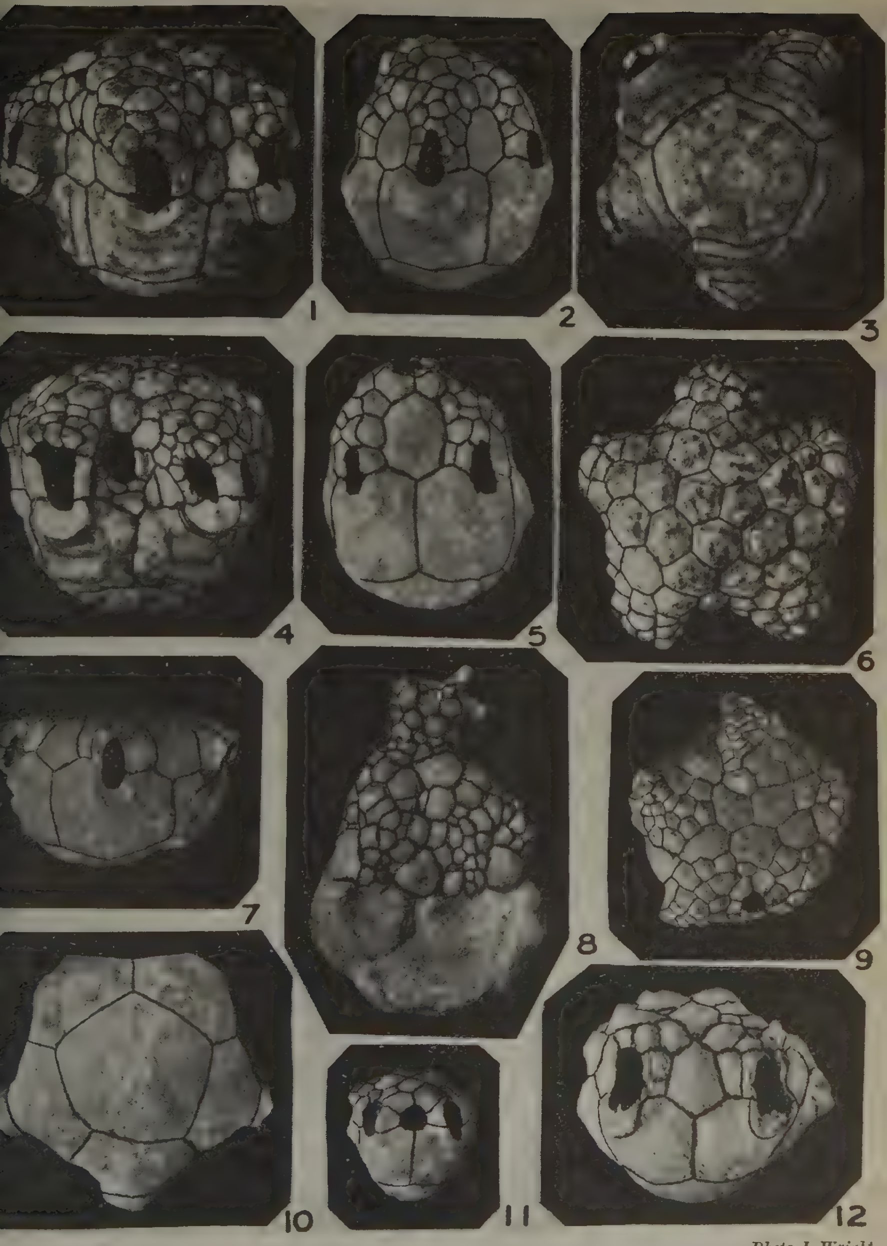

Photo J. Wright.

PLEUROCRINUS AND PLATYCRINUS.

with the tegmen in position. On this subject he says, "The integument over the abdominal cavity is protected by large and thick angular plates, and is capable of elongating itself in the centre into a proboscis, analogous to that in Actinocrinites." The Austins dispute this and say that "the mouth [anus] was unobtrusive". This may mean that the opening was in the lateral position, but none of the Austins' figures show this. Phillips gives a figure (pl. iii, fig. 20), of a complete calyx which he considers to be *P. rugosus*. In the Gilbertson Collection in the British Museum are specimens similar to the one figured by Phillips, and Mr. Bairstow has been good enough to send me Nos. E26286–8 which are labelled as this species. These three specimens agree well with Phillips's fig. 20. The plates of the dorsal cup are massive and ridged much as shown in Phillips's drawing. I find the anal opening is lateral just above the posterior radials apparently with no intervening plates. This is well shown in the smallest specimen E26288, but the other two are somewhat crushed and do not show the aperture so distinctly. If Miller's statement is correct for the species he describes the anal opening is on the tegmenal surface, in Phillips's specimens the opening is in the lateral position, therefore the two species are different.

Apart from other characters the present species differs entirely from Phillips's *P. rugosus* in the less thick and massive character of the cup plates and in this respect cannot be compared with it. On the other hand our species has more resemblance to the figure of *P. rugosus* given by the Austins (pl. 4, fig. 2*e*), but here again there are striking differences in the ornamentation and in the fewer number of plates in the tegmen in the Austins' specimen. One cannot of course be sure that the Austins' figure does really represent the species described by Miller. In any case, judging from all these figures and specimens, *P. inurbanus* certainly appears to be a larger species altogether. Of the seven specimens from Coplow six are more or less of the same size as the holotype.

(7) *Pleurocrinus coplowensis* sp. nov.

Pl. X, Figs. 17–20.

Diagnosis.—A small species; calyx higher than wide; dorsal cup short with flat basal circlet; ornament coarsely granular; tegmen about the same height as cup or slightly higher with swollen tubercular plates; anus lateral, directly above post. RR with no intervening plates.

Holotype.—J. Wright Coll. No. 2339.

Locality.—Coplow Knoll, Clitheroe.

Horizon.—C_1 (Parkinson, 1936).

Dimensions of Holotype.—Height of calyx over all, 16·4 mm.; height of dorsal cup, 7·5 mm.; greatest width across RR, 15 mm.

Remarks.—This is a neat little species which seems to be rather rare at Coplow. I have only found one really well preserved specimen which is here chosen as the holotype. The basal circlet is very flat and the tegmen is composed of rather numerous plates. The anal opening is particularly well shown with no plates between it and the posterior radials. The posterior inter-radius is occupied by three large plates, one on the left and right of the opening and the other at the top joining up with the tegmen. This species is chosen as the type of the group to which it belongs. In general shape it has some resemblance to *P. ellipticus* (Phillips) illustrated on Pl. X, Figs. 21–4, but differs in having a flatter basal circlet and a less elevated tegmen.

(8) *Pleurocrinus wanneri* sp. nov.

Pl. IX, Fig. 11.

Diagnosis.—A small species; calyx higher than wide; dorsal cup elongated, basal circlet conical; ornament coarsely granular; tegmen flat on top, about two-thirds height of cup, plates few with single tubercle on each; anal opening lateral, directly above post. RR without intervening plates.

Holotype.—J. Wright Coll. No. 2338.

Locality.—Knoll Wood, Newton in Bolland, Yorkshire.

Horizon.—C_2 (Parkinson, 1936).

Dimensions of holotype.—Height of calyx over all, 18 mm.; height of dorsal cup, 12·8 mm.; width of cup across RR, 16·5 mm.

Remarks.—This species is represented by three specimens, but two are somewhat obscured by matrix. The holotype, however, is in a good state of preservation and shows the species is also quite different from *P. ellipticus* (Phillips), and especially from the previous one *P. coplowensis* which it perhaps most closely resembles in that the basal circlet is not flat as in that species. The cup therefore is more elongated, the tegmen is relatively lower, and the tegmenal plates also are fewer in number. The posterior inter-radius is occupied by four plates instead of three as in *P. coplowensis.* The plates bounding the anal opening on the left and right are not so large and there are two plates instead of one joining up with the tegmen. Altogether this is an elegant little form and I have much pleasure in associating it with the name of Professor Wanner who has done so much to further our knowledge of the Timor crinoids.

POTERIOCRINIDAE Roemer (emend. Wachs. and Spring.).

POTERIOCRININAE Springer.

(9) *Pachylocrinus monensis* sp. nov.

Pl. XI, Fig. 3.

Diagnosis.—A rather small species; cup elongated, conical, anal area normal; arms long with one IBr and two tapering rami of secundibrachs to each ray; column round.

Holotype.—J. Wright Coll. No. 2340.

Locality.—Cass-ny-hawin, Isle of Man.

Horizon.—C_2 (Lewis, 1930).

Remarks.—Several specimens belonging to this species have been found at Cass-ny-hawin. The matrix in which they occur is a somewhat micaceous shale and specimens are difficult to remove intact. This species has some resemblance to *Poteriocrinus tenuis* Miller as figured by the Austins (pl. 10, figs. 5*a* and *b*), but the Austins' figures do not agree with Miller's (plates opposite pp. 67 and 71). In the cup figured by Miller the facets on the radials are horseshoe shaped and only occupy part of the radial whereas in the Austins' figures the facets are of the full width. It is doubtful therefore whether the Austins' specimen belongs to Miller's species. On the other hand, while our specimens agree fairly well with the Austins' figures as to the shape of the cup and the structure of the radials, the brachials in the Isle of Man specimens are much shorter and distinctly cuneiform with zigzag sutures and not parallel as in the Austins' specimen. The arms in our species, as shown by the holotype and other specimens, are rather long and are at least ten times the height of the cup. The primibrachs are long and narrow in the holotype but this character is not so pronounced in some of the other specimens where these plates are somewhat shorter.

(10) *Scytalocrinus beggi* sp. nov.

Pl. XI, Fig. 12.

Diagnosis.—A small species with five simple arms, one to each ray; brachials cuneiform; cup elongated, conical; plates smooth; column round.

Holotype.—J. L. Begg Coll.

Locality.—Cass-ny-hawin, Isle of Man.

Horizon.—C_2 (Lewis, 1930).

Remarks.—This species is provisionally referred to *Scytalocrinus.* Although in general shape it resembles the preceding species from the same locality, it differs from it entirely in the arm structure which is simple and consists of one arm only to each ray. In this respect it can be grouped with the three Scottish species also provisionally referred, for want of a better resting-place, to the same genus, viz. *S. covensis*, *S. pentonensis*, and *S. arbiglandensis* (Wright, 1934, p. 251). It seems very probable that a new genus will have to be created for all these forms and one or two others not yet described, the main characters of which are the possession of five simple arms and a cup more or less conical in shape with anal area of normal type. The Isle of Man specimen evidently belongs to this group although one could have wished that the anal side of the cup had been less obscured by matrix. Judging from the width of the cup across the radials, however, the anal area is probably of normal character. Even so, the more elongated shape of the cup and the longer and more uniformly uniserial brachials all indicate that it belongs to a distinct species. In two of the Scottish species the brachials show a tendency towards a biserial arrangement in the lower parts of the arms. There is no trace of this in the present species. The shape and arrangement of the brachials in the different species in this group seem to be very distinctive. In a unique specimen of a new species recently discovered in Fife the arms are heavy, very long, and, in contrast to all the other species, markedly biserial throughout their length. The cup is somewhat shallow-bowl shaped. This species will be described later when at the same time it is hoped to deal more fully with the present Isle of Man form and the Scottish species as a whole. The relationship of this group of five armed species to others possessing similar characters like *Poteriocrinus originarius* Trautschold, *Lophocrinus minutus* (Roem.), *Cromyocrinus simplex* Trautschold, *Ulocrinus doliolus* Wright, *Gilmocrinus iowensis* Laudon, etc., will also have to be considered.

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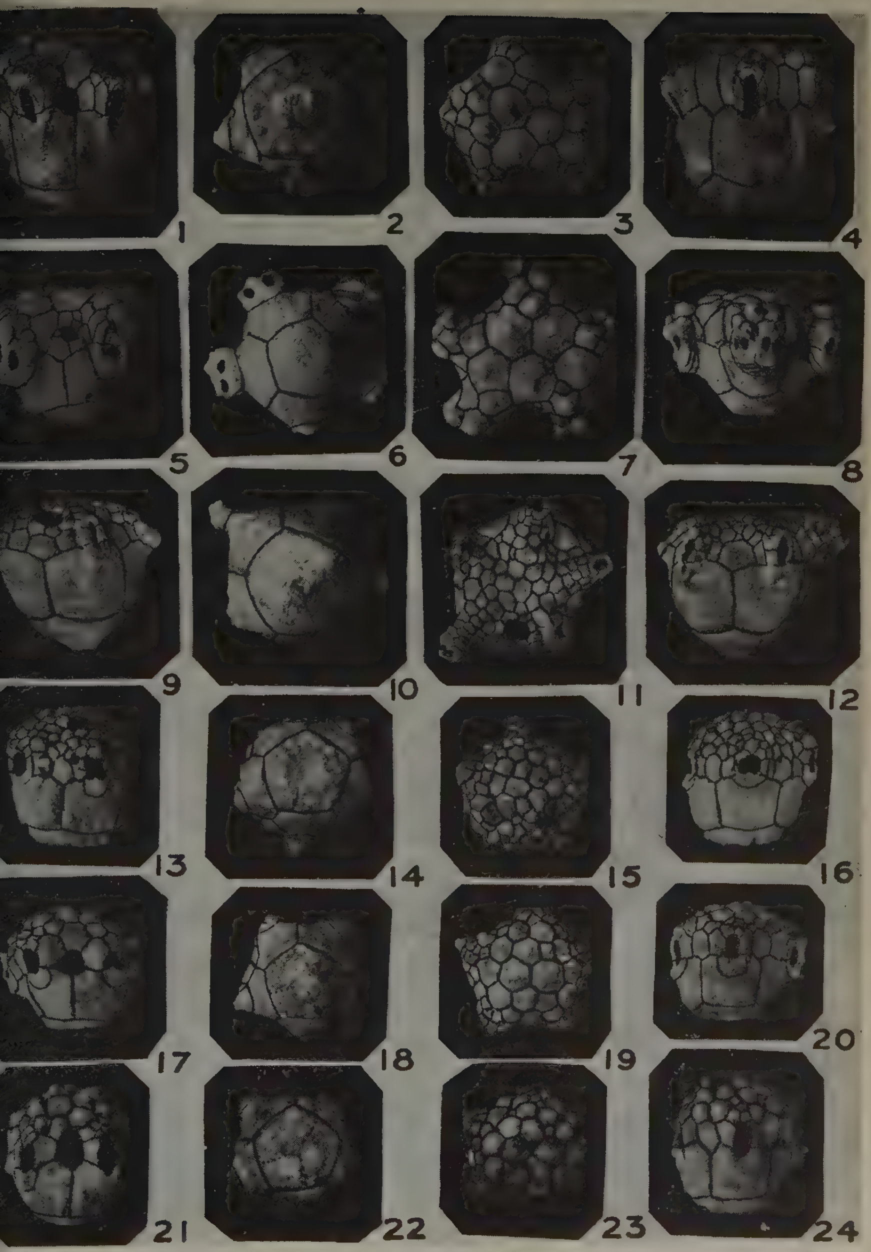
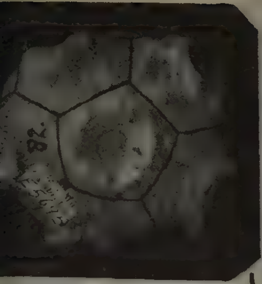


Photo J. Wright.

PLEUROCRINUS AND PLATYCRINUS.

[*To face p.* 286.



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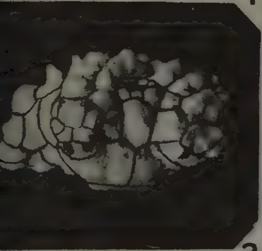

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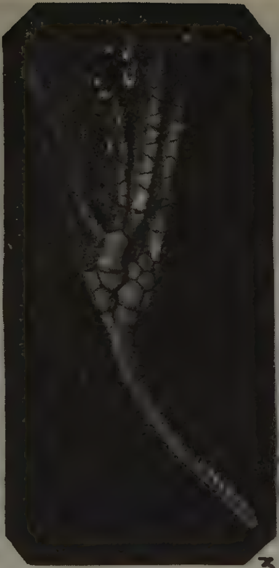

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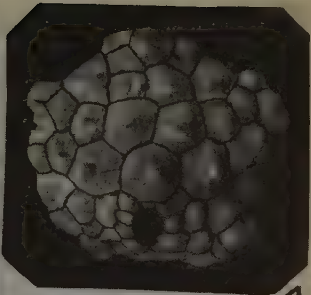

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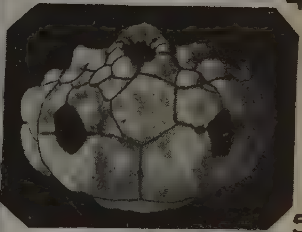

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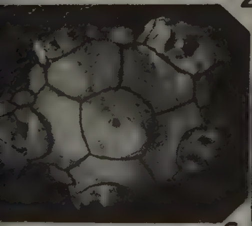

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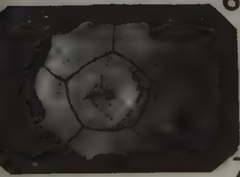

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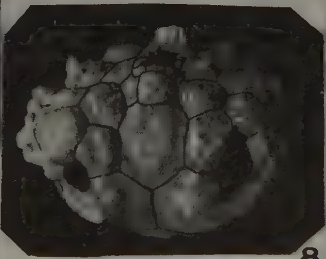

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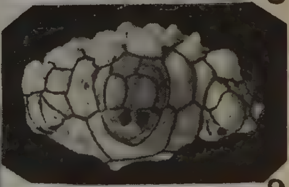

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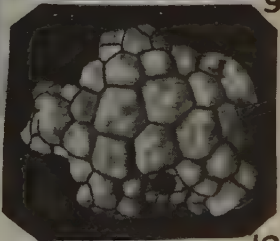

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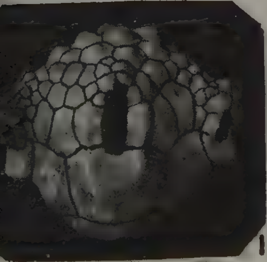

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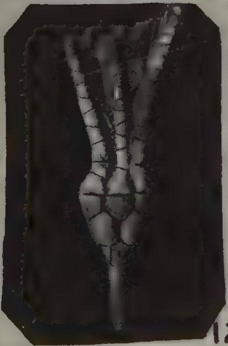

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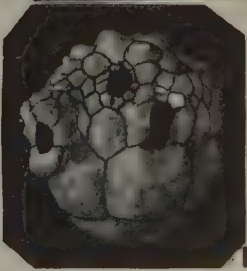

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Photo J. Wright.

Crinoids from the Isle of Man, Ireland and Lancashire.

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VI. EXPLANATION OF PLATES.

PLATE VIII.

FIGS. 1–7.—*Pleurocrinus grandis* sp. nov. from Balladoole, Isle of Man. Figs. 1, 2, 6, and 7, posterior, anterior, bottom, and top views of the holotype. Figs. 3 and 5, top and anterior views of a small specimen, and Fig. 4, anterior view of a somewhat larger specimen. All author's collection, nat. size.

PLATE IX.

Figs. 1, 3, 4, and 6, *Pleurocrinus inurbanus* sp. nov. from Coplow Knoll, Clitheroe, anterior, bottom, posterior, and top views of the holotype. Figs. 2, 5, and 8, *Platycrinus gigas* Phillips from Coplow Knoll, Clitheroe; Fig. 2, right antero-lateral view; Fig. 5, posterior view; Fig. 8, view of a flattened specimen from nearly the same position as Fig. 2, showing the prolongation of tegmen, full length of anal tube, and some spiniferous plates at the extremity. Figs. 7 and 9, *Platycrinus directus* sp. nov., anterior and top views of the holotype from Balladoole, Isle of Man. Figs. 10 and 12, *Platycrinus balladoolensis* sp. nov., bottom and anterior views of the holotype from Balladoole, Isle of Man. Fig. 11, *Pleurocrinus wanneri* sp. nov., posterior view of the holotype from Newton in Bolland, Yorkshire. All author's collection, nat. size.

PLATE X.

Figs. 1–4, *Pleurocrinus tuberculatus* (Miller), posterior, bottom, top, and anterior views of a calyx from Knoll Wood, Newton in Bolland, Yorkshire. Figs. 5–8, *Pleurocrinus coronatus* (Goldfuss); Figs. 5 and 7, posterior and top views of a specimen from Bellman Quarry, Clitheroe; the basal circlet in Fig. 5 is missing; Figs. 6 and 8, bottom and anterior views of another specimen from the same locality, Fig. 8 shows the true outline of the basal circlet. Figs. 9–12, *Platycrinus humilis* sp. nov., posterior, bottom, top, and anterior views of the holotype from Newton in Bolland, Yorkshire. Figs. 13–16, *Platycrinus* cf. *granulatus* Miller, posterior, bottom, top, and anterior views of a specimen from Coplow Knoll, Clitheroe. Figs. 17–20, *Pleurocrinus coplowensis* sp. nov., posterior, bottom, top, and anterior views of the holotype from Coplow Knoll, Clitheroe. Figs. 21–4, *Pleurocrinus ellipticus* (Phillips), posterior, bottom, top, and anterior views of a specimen from Coplow Knoll, Clitheroe. All author's collection, nat. size.

PLATE XI.

Figs. 1, 2, 4–10, *Platycrinus diadema* McCoy; Figs. 1, 4, and 5, bottom, top, and posterior views of a specimen in the Sedgwick Museum, Cambridge, regd. No. E5695, from Cleenish, Co. Fermanagh, Ireland; Figs. 2, 6, 9, and 10, posterior, bottom, anterior, and top views of a smaller specimen from Bellman Quarry, Clitheroe, author's collection; Fig. 7, bottom view of a dorsal cup from the same locality, author's collection, showing more clearly the character of the basal circlet; Fig. 8, posterior view of a large specimen from Bolland in the Yorkshire Museum, York. Fig. 3, *Pachylocrinus monensis* sp. nov., left posterior view of the holotype from Cass-ny-hawin, Isle of Man, author's collection. Fig. 12, *Scytalocrinus beggi* sp. nov. from the same locality, the holotype, J. L. Begg collection. Figs. 11 and 13, *Platycrinus bollandensis* sp. nov., left antero-lateral and posterior views of the holotype in the Yorkshire Museum, York. All figs. nat. size.

REVIEW.

GROUND WATER. By C. F. TOLMAN. pp. xvii + 593, with 189 text-figures. New York and London: McGraw Hill Company, 1937. Price 36*s*.

IT is scarcely necessary to enlarge on the importance of the scientific study of ground-water, or sub-surface water, from many points of view, and it is somewhat surprising to find, as stated in the preface, that this work is the first treatise in English entirely devoted to the subject. The author is Professor of Economic Geology at Leland Stanford Junior University, and the subject of it is of course of immense importance in the Western States, where prosperity or even existence depends on water supply. The outlook is therefore frankly American and shows the usual American thoroughness in matters of economic geology. In that country both floods and droughts have of late attracted much attention to water problems and the same is true of England, on its appropriate scale. Hence the thorough and systematic treatment of the subject in this book cannot fail to find their application also in this country and in the numerous dry areas of our Dominions, Colonies, and Protectorates.

R. H. R.

ANNOUNCEMENT.

THE ASSOCIATION FOR THE STUDY OF SNOW AND ICE.

The idea of forming the Association for the Study of Snow and Ice originated from the desire of the British members of the International Commissions on Snow and on Glaciers respectively to establish in this country a permanent body to encourage research on the practical and scientific problems of snow and ice, and generally to stimulate interest in the subject. Several meetings have taken place, and the Association can now be said to be well established. Meetings are held every three months for the purpose of reading and discussing papers, and reports of these are circulated to members. In addition, individual members are engaged on practical work and researches of various kinds.

The present Chairman is Mr. Gerald Seligman (Chairman of the British Group of the International Commission on Snow), and the Vice-Chairman, Mr. J. M. Wordie (President of the International Commission on Glaciers).

Membership of the Association is open to geographers, geophysicists, meteorologists, geologists, physicists, mountaineers, ski-runners and others who can provide evidence that the study of snow and ice is, or has been of scientific or practical interest to them. Particulars of election, subscription (which is only nominal at the moment), etc., may be obtained from the Honorary Secretary, Miss P. B. Lapworth, Warren Close, Coombe Hill Road, Kingston Hill, Surrey.

THE
GEOLOGICAL MAGAZINE
VOLUME LXXV.

No. VII.—JULY, 1938.

ORIGINAL ARTICLES.

The Age of the Rocks and Topography of Middle Northern Iceland.

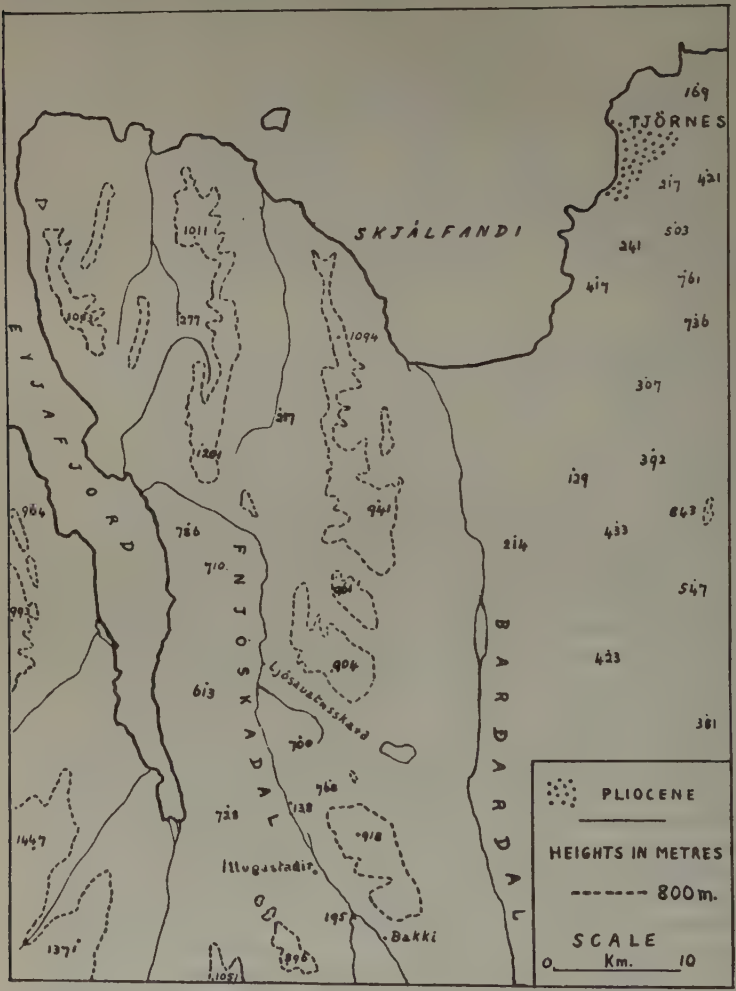
By L. Hawkes.

NORTHERN Iceland between Skagafjord on the west and Skjálfandi Bay on the east is a deeply dissected upland built up of plateau basalts with subordinate intercalations of clastic volcanic sediments. The main valley, the Eyjafjord, is traceable northwards as a groove in the sea floor down to −500 metres. To the east of the upland the country is less elevated; marine Pliocene deposits are present in the Tjörnes peninsula, and recent lava flows are prominent. The contrasted regions adjoin along the Barðardal fault running N.–S. and marking the western boundary of the great graben which has been the site of Recent and Quaternary volcanic activity. Thoroddsen considered the upland rocks to be Tertiary (Miocene) in age, and that the Pliocene sediments had been laid down in a bay formed after the faulting and erosion of the older series.

In 1905 Pjeturss (pp. 20–5) reported the find of glacial beds in the upper part of the basaltic series of the upland west of Barðardal and took them as evidence of a Miocene glaciation. Later these beds and the basaltic series 400 metres thick which overlies them were assigned to the early Quaternary and considerable areas of Iceland previously regarded as Tertiary are on Pjeturss's maps depicted as "Tertiary and Quaternary" (1908, pl. 5, 1910, p. 2). This was a startling change involving the corollary that a fjord and mountain topography comparable with that of the Tertiary regions of the Western Highlands of Scotland had been wholly fashioned since the oncoming of the Quaternary Ice Age, a conclusion which has been adopted by Nielsen (1933, pp. 279, 281). In 1937 I examined the sections upon which Pjeturss based his conclusions, and in what follows I give reasons for rejecting the hypothesis of the glacial origin of the beds and review the evidence bearing upon the age of the rocks and topography of middle Northern Iceland.

The Age of the Older Volcanic Series of Iceland.

Even in recent accounts of Icelandic geology the older plateau basalt series is stated to be of Miocene age, a view which dates from



Text-fig. 1.—The eastern part of the Skagafjord-Skjálfandi upland region, and part of the graben to the east. Based on the Generalstaben's Map of Iceland, sheet no. 4, 1/250,000.

Heer's determination (1868) of the age of the plant remains found between the basalts in Iceland, Greenland, and the British Isles, and which ignores later work indicating an Eocene age. Gardner (1887, p. 299) inferred an Eocene—probably Lower Eocene—age for the Mull flora and from examination of more material Seward and Holttum (p. 89) support this conclusion. The ages of the floras and faunas found between the basalts of Greenland are now given as Lower and Middle Eocene, and Oligocene (Koch, pp. 114–15). Gardner (1885, p. 94) writes that the Icelandic plant beds are very much newer than the Mull flora and " might, from their general character, be assigned to even so late a stage as the Miocene " but as this is based on determinations of some 40 species of which " there are only a few that seem to rest on a sure basis " and as the relative stratigraphical positions of the beds in Mull and Iceland was inferred from an unsound petrographical correlation, little weight can be given to so tentative an opinion. Other evidence is cited below indicating that the volcanic activity of the Thulean province came to an end before Miocene times, and the fossil evidence cannot be said to conflict with this.

THE EVIDENCE FOR FORMER GLACIATIONS.

Before examining Pjeturss's evidence for the glacial origin of the beds of the upland region some remarks are offered respecting the criteria from which the glacial origin of deposits may be deduced. Differences of opinion as to whether particular beds in Iceland are glacial or not is common, and this is not surprising when it is remembered that in that country glaciers and active volcanoes have co-existed throughout Quaternary times and down to the present day, and that volcanic deposits can simulate glacial boulder beds to a very puzzling degree. Striated pavements, deposits carrying striated boulders, and varved clays are reliable evidences of glacial conditions, but in the special circumstances of repeated volcanic " extrusion " beneath an ice cover these evidences are likely to be wanting, and the question arises whether the accumulations resulting from sub-glacial activity have special characteristics by which they may subsequently be recognized.

Recent eruptions beneath the Vatnajökull ice cap have been studied by Nielsen and his co-workers, and from his descriptions of the deposits formed and his account of the rocks of the " Palagonite Formation " which is believed to contain much material " extruded " beneath ice, it appears that the deposits are not distinguishable from those laid down by volcanic action under water, unless they contain striated foreign boulders dropped in from the melted base of the ice cover (Nielsen and Noe-Nygaard, p. 15). The magma forms pillow lavas, and individual pillows and irregularly shaped masses may occur widely separated in a sand of glassy grains—Nielsen's " basaltkuglebreccie ": the glassy selvages of the basalt masses may be one inch thick. These are the characteristics of water-cooled extrusives: similar rocks are found in the Pliocene marine series at Tjörnes and at the base of the volcanic series in Skye (*Summary of Progress*, pp. 77–9).

Drastic chilling of basic magma produces a tachylyte devoid of iron ores and translucent in thin section, for which Peacock (1926, p. 56, and Peacock and Fuller, 1928, pp. 371–4) has revived the name sideromelane. He has traced its alteration to the hydrogel palagonite—a common constituent of the Quaternary rocks of Iceland—and considers that the palagonite was formed from the sideromelane resulting from "the ultra-rapid chilling effect of the Pleistocene ice sheet on the products of sub-glacial volcanoes" (Peacock, 1926, p. 67). Sideromelane is known not only in fragmental volcanic ejecta but as the glassy selvages of the basalt masses of the kuglebreccie described above, and it may occur as a superficial skin of subaerially chilled lava. Barth (p. 37) in explanation of a sideromelane volcanic ash from the Vatnajökull speaks of "the chilling effect of the Vatnajökull ice-sheet on basalt lava of sub-glacial outbursts.

There is some danger that these writings may give rise to the belief that ice has a superior chilling effect on magma, and that sideromelane or palagonite may be taken as evidence of glacial conditions. The ice at the base of the Icelandic glaciers is—and probably was—at 0° C., and this temperature is so close to that of most natural waters that no differences in the effects of water and ice chilling are to be expected: furthermore any contact of ice and magma can hardly be more than instantaneous, and the chilling of sub-glacial volcanic products must be due to water contact. Nielsen (1937, p. 85) in his interesting account of the 1934 eruption beneath the Vatnajökull estimates the amount of water produced by the ice melting to have been 10,000 million tons. The widespread occurrence of sideromelane and palagonite in the continental Quaternary deposits of Iceland undoubtedly indicates the presence of water over large areas and the existence of an ice cover may well be adduced to account for these conditions; what it is desired to emphasize here is that sideromelane and palagonite are not in themselves indicators of glacial conditions.

THE SUPPOSED GLACIAL BEDS IN THE UPPER BASALTIC SERIES.

The beds regarded by Pjeturss as glacial occur between the plateau basalts of the upland west of Skjálfandi and are exposed on the eastern side of Fnjóskadal and on both sides of Ljósavatnsskarð (Pjeturss, 1905, pp. 22–6). The "moraines" are described as boulder beds, conglomerates, and sands resting upon a striated dolerite pavement, the best locality being Skriðugil in Fnjóskadal. In 1936 two Cambridge students, P. S. Adler and J. A. Campbell, visited Iceland and at my suggestion made an examination of the beds in Fnjóskadal and Ljósavatnsskard. They reported that they could find no indications of glacial origin of the beds and their descriptions and rock collections suggested a fluviatile and pyroclastic character; the locality of Skriðugil was not, however, certainly identified.

In 1937 I followed in Messrs Adler and Campbell's footsteps in Fnjóskadal and can support their conclusions. Skriðugil does not appear on the Generalstaben's map (sheet 73) nor is such a name known to the present inhabitants of Fnjóskadal, but the succession shown in the gills on the eastern side of that valley between Illugastaðir and Bakki is similar to that reported by Pjeturss from Skriðugil, so there is little doubt that the so-called "moraines" have been examined. Space need not be occupied in describing the deposits in detail: in Fnjóskadal they grade from conglomerates with sub-angular boulders up to a foot in length, through sands to fine clays, some of which are white and are deposits of the finest acid vitric ash. No striated boulders or pavements were seen, there are no pronounced erosion surfaces beneath the various sedimentary intercalations, and there is no tectonic discordance between the basalts below and above them: similar deposits are found at various horizons in the older Tertiary series of Iceland. With the rejection of a glacial origin for these beds the overlying basalts need no longer be regarded as of Quaternary age.

THE TOPOGRAPHY OF THE UPLAND REGION.

From any high vantage point the general accordance of summit levels of the region between Skagafjord and Skjálfandi is clearly seen, and the excellent maps of the Generalstaben (1/100,000, sheets 52, 53, 61, 62, 63, 71, 72) show the valleys to be incisions in a plateau varying in height from 1,400 to 900 metres. This surface is not parallel to the dip of the basalts, and faults do not step it: it is thus an erosional peneplane produced after considerable tectonic disturbance. The surface was probably produced by subaerial or marine erosion and subsequently elevated, but the possibility that a highland ice sheet may have been an instrument of peneplanation (F. E. Wright, p. 724) must not be forgotten. The Pliocene deposits of Tjörnes rest on an eroded and tilted surface of older basalts (Barðarson, pp. 15–17) and are overlain by later lavas. No Pliocene deposits are known in the upland region west of the Barðardal fault, and the simplest reading is that the fault was pre-Pliocene. The preparation of the upland peneplane and its deep dissection is a geological work of such magnitude that its commencement may well be assigned to the end of the Eocene or Oligocene periods, a view which is consonant with the data afforded by other remnants of the Thulean province.

OTHER REMNANTS OF THE THULEAN PROVINCE.

Only two localities are known where datable pre-Quaternary rocks overlie the Thulean basalts: Tjörnes in Iceland and Lough Neagh in Ireland. The Tjörnes deposits are correlated with the English Crag (Barðarson, pp. 111–14) and the Lough Neagh clays are assigned to the Older Tertiary (W. B. Wright, p. 485). The Lower Eocene sediments of the Cape Dalton area of East Greenland lie "at or near the top of the basalt series" (Wager, 1933, p. 153). The other evidence regarding the date of the cessation of the Thulean activity is physiographic. Everywhere we have the formation of extensive peneplanes, their uplift and deep dissection—impressive indications of a lengthy post-volcanic period. Post-dating the igneous activity in Scotland, the formation of the 3,000 ft. platform is referred to the mid-Tertiary (Hollingworth, p. 76). Ødum (p. 203) suggests that the 300 m. peneplane of the Faeroe Islands was prepared in mid-Tertiary times. In Eastern Greenland a peneplane rising in places to 8,000 feet cuts gently across the lava flows and Wager (1933, pp. 153, 154) suggests that this was formed and uplifted by Miocene times, in which period the ice cap may have been initiated.

THE VOLCANIC HISTORY OF ICELAND.

Volcanic activity has persisted in Iceland from Pliocene times to the present day. No evidence has as yet been obtained of any activity in Miocene or Oligocene times, and until such is forthcoming the present cycle may be regarded as a separate one and not a continuation of the Thulean cycle. It may be noted that in Spitsbergen the older lavas are of Cretaceous or early Tertiary age, whereas the later volcanoes are of Glacial or post-Glacial age.

The older Tertiary basalt series of Iceland is estimated to have a thickness of at least 14,000 feet: in Greenland the volcanic series attains a thickness of 7,000 metres (Wager, 1937, p. 415) and in the Faeroes 15,000 feet (Walker and Davidson, p. 894). All the lavas appear to have been extruded subaerially and evidence of glacial conditions is lacking. As the building of such high plateaux would probably have resulted in glaciation even in Eocene times, it would suggest that the outpouring of the lavas was accompanied by a sinking of the land surface. Was the Thulean activity due to a rise of temperature in the sub-crust whereby the lighter liquid progressively formed below continuously rose to the surface of the denser solid cover, thus providing a convenient means of heat escape?

THE LAND BRIDGE.

Scandinavian botanists still call for a Greenland-Scandinavian land connection in Quaternary times in order to account for certain features of the Norwegian mountain flora (Nordhagen, p. 271). The

Thulean land area was broken up and the North Atlantic formed in pre-Pliocene times. The submarine valleys in the continental shelf of Iceland indicate a former base level of erosion of −500 metres, and a sea-level at this position would give a Greenland-Europe land connection (Nansen, pp. 75–86, 173). The date of the continental shelf of Iceland is given as pre-Pliocene by Thoroddsen and Pliocene and Pleistocene by Nansen, and furthermore it is not clear whether the grooving of the shelf pre- or post-dated its formation. There is nothing of importance to be added to the full discussion of the question given by Nansen (pp. 167–194), and the date of the last land connection remains unknown.

CONCLUSIONS.

The following sequence of events is suggested for middle Northern Iceland. Later work may make modification necessary, but it is claimed that it does no violence to the facts as at present known, and that it is in accord with the geological histories deduced for other remnants of the Thulean province.

First volcanic period—Outpouring of the Thulean basalts. Eocene (Oligocene ?)

Tectonic disturbance, formation of the upland peneplane, its initial erosion and uplift along the Barðardal fault—(Oligocene ?) Miocene.

Deposition of the marine sediments of Tjörnes—Pliocene

Second volcanic period—Pliocene—Present day.

Glaciation—Quaternary—Present day.

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Andalusite and Sillimanite in Uncontaminated Igneous Rocks.

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THE occurrence of andalusite and sillimanite in unaltered igneous rocks is, according to the orthodox view expressed in most standard textbooks (see, e.g., Tyrrell, 1934, pp. 50, 164; Shand, 1927, pp. 62, 146; Grout, 1932, p. 230), always to be ascribed to contamination of magmas by highly aluminous sedimentary or metamorphic rocks. Having been given cause to doubt the correctness of this view by the recognition at Pyramid Hill, Victoria, of andalusite-bearing granites and aplites in which evidence of assimilation is lacking, I was then very interested to discover that the opinion has often been expressed, and evidence adduced in support of it, that both andalusite and sillimanite may be normal pyrogenetic constituents of igneous rocks.[1] That is, they may under certain conditions crystallize from uncontaminated magmas. Some authors, while admitting that andalusite and sillimanite may crystallize from magmas, regard such pyrogenetic occurrences of these minerals as caused by the development of local excess of alumina, due to the assimilation of shales (e.g. Wells, 1931; Shand, 1927, p. 62). Others do not make their position clear, merely classing andalusite and sillimanite as assimilation minerals (*sic*), but Tyrrell goes so far as to state that they are " never of pyrogenetic origin " (1934, p. 50). Because of the reliance that is placed upon accessory minerals in igneous rocks as indicators of consanguinity of magmas and of the role of assimilation and other processes in petrogenesis, it is important that the status of each mineral should be thoroughly understood. In most classifications of accessory minerals andalusite and sillimanite are either classed as " contamination accessories " (Wells, 1931) or grouped with minerals that are commonly due to contamination (Wright, 1932), and Wright regards them as " of little value for correlation purposes ". Chatterjee, however, was able to use andalusite as an indicator, on the one hand, of relationship between the Falmouth and Bodmin Moor granites, both of these containing a purple variety in fair amount, and, on the other, of the distinction of these granites from those of Dartmoor and St. Austell, in which andalusite is colourless and rare. The rare, sporadically developed andalusite in the Dartmoor granite is considered by Brammall and Harwood (1923) to be a contamination mineral, but Teall suggested (1887) that the andalusite in the Cheesewring granite is probably an " original constituent " (i.e. not mechanically incorporated with the granite, as strew from xenoliths or wall rocks), and the relative abundance and uniformity of distribution of andalusite in the normal type of the Bodmin Moor granite, as exhibited at the Cheesewring (see Ghosh, 1927), lend support to this suggestion.

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[1] Normal.—Not related to contamination processes. Pyrogenetic.—"Formed from igneous magmas" (Tyrrell, 1934, p. 47).

In this paper an attempt will be made to decide whether andalusite and sillimanite can crystallize as pyrogenetic minerals, and, if so, whether they are to be found only in contaminated rocks or can develop as normal constituents of uncontaminated magmas. I assume in what follows that granitic magmas, with which we shall be especially concerned, do exist as distinct from granitoid rocks developed by transfusion, anatexis, or similar processes that may affect sedimentary rocks. If this assumption should prove to be incorrect, there would appear to be no good reason for regarding andalusite and sillimanite as abnormal constituents of granites, since these would then be inherently contaminated rocks.

In attempting to gather data from published work on the above points at issue, we need not consider occurrences of andalusite and sillimanite which have been demonstrated to be due to assimilation (e.g. in the norites and gabbros of parts of Aberdeenshire—Read, 1923, and in the Dartmoor granite—Brammall and Harwood, 1923), and if we limit the discussion to rocks in which either these minerals are common accessories, or concerning which it has been suggested or appears to be possible that assimilation was not responsible for their development, a weighted set of data is arrived at, from which some significant facts emerge. The following is a list, weighted in this way, of all the occurrences known to me.

ANDALUSITE-BEARING GRANITES.

(1) Two-mica granite (Cheesewring Type), Bodmin Moor (Teall, 1887; Ghosh, 1927). Contains abundant purple andalusite which was regarded by Teall as an "original constituent".

(2) Two-mica granite, Falmouth (Ghosh, 1928). Contains abundant purple, rare colourless andalusite.

(3) Two-mica granite (pink type), Eskdale, Cumberland (Simpson, 1934). Contains colourless and also pink andalusite, regarded as pyrogenetic and not due to contamination, but probably derived from alumina-rich residual portions of the magma, developed by normal differentiation processes.

(4) Two-mica granite, Solitude, Globe District, Arizona (Ransome, 1903). It is suggested that the andalusite may be regarded as a "primary mineral", owing to the absence in it of carbonaceous inclusions.

(5) Two-mica micro-granite, Hennberg (Hainberg), near Weitisberga, Thuringia (Müller, 1882). Occurs as dykes in biotite-granite and in metamorphic schists. It is pointed out that the dykes in the granite have had no opportunity [say, rather, little opportunity] of assimilating aluminous material, so that the andalusite is regarded as a "normal" constituent.

(6) Two-mica granite, Upper Achertal, Schwarzwald (Regelmann, in an Inaugural Dissertation, Heidelberg: quoted in Johannsen, 1932, vol. 2, p. 163, and Rosenbusch, 1907, vol. 2, p. 57). This granite contains abundant and uniformly distributed andalusite, and is the only occurrence admitted by Rosenbusch to be a "normal granite" out of several he lists as containing andalusite.

(7) Two-mica granite, Klause, near Herrenalb, Schwarzwald (Cohen, 1887). The andalusite-bearing granite occurs as dykes traversing biotite-granite.

(8) Aplitic tourmaline-granite, Alt-Zschillen, near Wechselburg, Saxony (Cohen, 1887). Contains abundant andalusite.

(9) Two-mica tourmaline-granite, Laach, near Weiler, Vosges (Cohen, 1887).

(10) Biotite-granite, Moslawina, Croatia (Cohen, 1887). Contains large idiomorphic andalusite crystals.

(11) Biotite-granite, Rochesson, Vosges (Cohen, 1887).

(12) Granite, Raumunzach, Schwarzwald (Cohen, 1887).

Notes.—Rosenbusch (1907, p. 57) claims that all the occurrences listed by Cohen are "*Gneissgranite*" and not "normal" granites. Cohen, however, makes the definite claim that they are all normal, and that the crystallization of andalusite in them is not to be ascribed to "local" circumstances. Since Rosenbusch would describe pegmatitic and tourmaline granites as abnormal, his application of this term to a granite does not necessarily imply that it is contaminated, and we may therefore tentatively assume the validity of records 7, 8, 9, and 10. Other records given by Cohen and also by Rosenbusch (1907, p. 56), and by Harker (1891, p. 283) may be discarded as doubtful.

(13) Two-mica granite, Pyramid Hill, Victoria. This granite contains andalusite that is abundant and uniformly distributed enough to be present in every slide. It is intrusive into a porphyritic "giant" granite that does not contain andalusite. No xenoliths have been observed in the andalusite-bearing granite, and they are very rare and sporadically developed in the giant type. Assimilation processes are thus subordinate in the giant granite, and the later andalusite-bearing granite must have had still less opportunity of becoming contaminated, having been shielded by the giant granite from contact with the sedimentary country rocks. The andalusite-bearing granite is leucocratic, and the subordinate amount of biotite it contains is a further indication of absence of contamination.

SILLIMANITE-BEARING GRANITES.

(1) Muscovite-granite, Learable Hill, Strath Hallidale complex, Sutherland (Read, 1931, p. 162).

(2) Muscovite-granite, Cnoc na Beiste, Strath Hallidale complex (Read, 1931, p. 162). Both these rocks contains a little biotite as well as muscovite. In Read's opinion "the presence of sillimanite in these leucocratic granites is not to be attributed to an excess of alumina arising by assimilation of pelitic rock." The contaminated granites of the district are *sur-micacé*, the supposedly uncontaminated ones leucocratic.

APLITES (all available records).

(1) Veins in biotite-granite, Hennberg, Thuringia (Müller, 1882). Andalusite abundant: regarded as a normal constituent.

(2) Veins and patches at Hirschgrund, Harz, in the composite granitic Bodegang (Erdmannsdörffer, 1924). The andalusite is not regarded as an assimilation-product but as the result of the transference to the contact rocks of alkali silicates, leaving an excess of silicate of alumina behind. This gives rise to muscovite in some places, to topaz and garnet in others, and to andalusite at the "root" (Wurzel) of the dyke near the parent granite, where the temperature was highest. It will be noted that according to this suggested mode of origin, andalusite should occur only in the marginal zones of intrusions, and not in parts more remote from the contact, which could not react upon the wall rocks. It could not, therefore, be regarded as a normal constituent.

(3) Veins in granite, Jersey (Wells, 1931). Andalusite occurs frequently in these aplites, and also in xenoliths in the granite at Les Rouaux.

(4) Veins in the Strath Hallidale complex, Sutherland (Read, 1931). These contain sillimanite, regarded by Read as not the result of contamination.

(5) Veins in andalusite-bearing granite, Pyramid Hill, Victoria. These contain abundant andalusite, but no xenoliths or other evidences of assimilation. The granite they traverse also contains no xenoliths.

(6) A dyke at Warburton, Victoria (Edwards, 1932). This contains abundant andalusite, but traverses andalusite hornfelses which it may have assimilated.

PEGMATITES.

References to the occurrence of large andalusites in pegmatites are not uncommon (Zirkel, 1893, Bd. 1, p. 387; Erdmannsdörffer, 1924, p. 125), but details concerning such occurrences are not often given. Murdoch (1936) records pegmatite dykes at Winchester, Cal., containing both andalusite and sillimanite; Mäkinen (1913) describes pegmatite from Tammela, Finnland, containing idiomorphic prisms of andalusite 7–8 cm. long, surrounded by quartz and potash felspar. Von Gümbel (*fide* Harker and Marr, 1891, p. 284) mentions it as occurring in pegmatite veins in Bavaria.

GREISEN.

Devoke Water, Eskdale, Cumberland (Simpson, 1934). Andalusite occurs with topaz and quartz in a pure white greisen without any evidences of assimilation.

DISCUSSION.

The occurrence of andalusite as large and well-formed crystals in pegmatites leaves little room for doubt that it can, under certain circumstances, develop as a normal pyrogenetic mineral, and support for this conclusion is afforded by its presence in aplite veins and patches in granites. It is improbable that xenolithic strew in the granites would be expressed from the main mass by filter press action along with the liquids that give rise to the aplites, and, furthermore, the subordinate amount of biotite in most andalusite-bearing aplites indicates that the products of xenolithic strew are not concentrated in them. This argument does not apply to ions added to the magma by reciprocal reaction with xenoliths and wall rocks, but where the parent granite shows little or no visible contamination effects, as for example at Pyramid Hill and Eskdale, there is every reason to regard the andalusite in the aplites as a normal constituent. These remarks also apply to sillimanite, although the conditions requisite for the pyrogenetic development of this mineral appear to have been attained much less frequently than for andalusite. The development of sillimanite in the contaminated norites and gabbros of Aberdeenshire, as described by Read, clearly indicates, however, that this mineral can be of pyrogenetic origin, though in this case the necessary alumina excess was generated by assimilation of rocks of sedimentary origin.

It is very probable that some significance should be attached to the frequency with which andalusite (and less commonly sillimanite) occurs, among the plutonic rocks, in two-mica granites. Many of these andalusite-bearing granites contain tourmaline, topaz, and other minerals serving to indicate that we have to deal with masses enriched to some extent in late magmatic concentrates, as indeed the essential nature of the rocks themselves, which are amongst the most acid types that are found as plutonic masses, also shows. Taken with the occurrences in pegmatites and aplites, this fact of distribution might lead one to suspect, from *a priori* reasoning, that alumina in excess of the requirements of the felspars and micas is sometimes present in liquid phases generated as a result of normal differentiation processes in acid granites. Niggli (1920, p. 179) and Read (1931, p. 163) have recognized the possibility that such alumina excess may arise in magmas, and Niggli suggests that the alumina is carried as aluminium halides, alkali aluminates, and similar compounds. In discussing homogeneous equilibria in magmatic melts, Niggli (1925) also refers to aluminium silicate. He notes that $[SiO_5]Al_2$ " certainly participates in reactions with other molecules ", but remarks that, owing to the possibility of such reaction, andalusite and sillimanite will separate from magmas only under special circumstances.

Further direct evidence that alumina in excess of the requirements of the felspars and micas may exist in liquid phases developed from granitic magmas is afforded by the mode of occurrence of topaz, a mineral which consists essentially of aluminium silicate in combination with fluorine and hydroxyl. Idiomorphic topaz crystals, as is well known, occur in vugs in granites, indicating clearly that the topaz crystallized directly from the silicate solutions, and did not replace felspars or other minerals metasomatically. Similarly, replacement bodies of topaz which consist almost entirely of this mineral (see, e.g., Salomon and His, 1888, on *Topazfels*) show that aluminium silicate, carried in solution, must have been added to the replaced rock mass. Shand (1927, p. 128) includes primary topaz among the minerals characteristic of his peraluminous group of igneous rocks, along with muscovite, biotite, corundum, tourmaline, almandine, and spessartite. If topaz is rightly included in this list, and the occurrence of pyrogenetic andalusite and sillimanite be admitted, then it would appear that the latter two minerals should also be included in it. In view of the similarity in the conditions of stress, temperature, and ionic mobility that must exist between the contact zones adjacent to intrusions and the intrusions themselves, it is clear that physical factors cannot be appealed to for the exclusion of andalusite from the ranks of pyrogenetic minerals, for it is most commonly developed in metamorphic aureoles. The inhibiting factor, if any, must be chemical, and as we have already seen in considering pegmatites, aplites, and the occurrence of topaz in vugs, that solutions capable of precipitating aluminium silicate do arise as apparently normal differentiates from granitic magmas, this factor, too, can probably be eliminated.

The significance of the large number of records of apparently primary andalusite in two-mica granites may now be discussed. In many of these rocks muscovite develops by replacement of potash felspar (replacement muscovite). This process may come about in two ways, which may be represented as follows :—

$$(1)\quad \underset{\text{(K-felspar)}}{3KAlSi_3O_8} + H_2O \rightarrow \underset{\text{(muscovite = sericite)}}{KH_2Al_3Si_3O_{12}} + K_2SiO_3 + 5SiO_2 \quad \text{(Tyrrell, 1934, p. 309)}$$

$$(2)\quad \underset{\text{(K-felspar)}}{2KAlSi_3O_8} + 2Al_2O_3 + 2H_2O \rightarrow \underset{\text{(muscovite)}}{H_4K_2Al_6(SiO_4)_6} \quad \text{(Alling, 1936, p. 205)}$$

The first of these mechanisms involves the selective removal from potash felspar of potassium silicate and silica, leaving a residue of muscovite. The second involves the addition of Al, O, and H atoms to the felspar, probably from aqueous solutions rich in alumina. I regard it as highly probable that an additive process essentially equivalent to that represented in equation (2) takes place in acid granites, because the crystallization of primary muscovite in these rocks indicates that solutions sufficiently rich in alumina to permit muscovite to crystallize are actually developed in them (and we have seen that there is other evidence that such Al-rich solutions exist). Furthermore, the removal of aluminium silicate and silica from felspar as in equation (1) would involve a considerable decrease in volume in the felspar. Evidence of this would be afforded by the partial breakdown of the form of the felspar, unless other minerals, such as quartz, should crystallize along with the replacing muscovite. The characteristically well-crystallized muscovite, unaccompanied by quartz or other minerals, found in most late-stage felspar replacements in igneous rocks (as opposed to sericitization), points rather to the addition of the requisite Al, O, and H, with a slight resultant increase in specific gravity over that of the original felspar.

Replacement muscovite, therefore, indicates the existence of peraluminous liquid phases containing "unattached" alumina, a condition which is quite compatible with the crystallization of aluminium silicate from the magmas of which these liquid phases are derivatives. Thus may be partly explained the fact that it is chiefly from those uncontaminated igneous rocks that contain muscovite—that is the muscovite-bearing granites, pegmatites, and aplites—that what appears to be primary pyrogenetic andalusite has been recorded. Why aluminium silicate and potash felspar are not mutually incompatible solid phases, and why some muscovite-bearing granites, pegmatites, and aplites should contain andalusite or sillimanite and others not, remain to be elucidated. It cannot be maintained that aluminium silicate crystallizes only from the final liquors permeating through a crystal mesh of earlier-formed solid phases, and thus some "special conditions" (Niggli), perhaps involving paucity of volatile constituents, or the slow diffusion of ions towards crystallization centres, still have to be invoked. I think that the evidence above outlined does indicate, however, that there is at least good cause to doubt the correctness of the belief that andalusite and sillimanite are always contamination minerals when they occur in igneous rocks.

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Notes on the Geology of the Lizard Peninsula.
No. 1. Some Mullion Rocks.

By J. B. SCRIVENOR.

BEFORE I went to Malaya in 1903 I had worked for two field-seasons in Cornwall as a very junior member of the staff of the Geological Survey, and since my retirement in 1931 the old interests in Cornwall have attracted me, with the result that from 1935 onwards I have been doing field-work each year in the Lizard Peninsula. My original object in going to this part of Cornwall, armed with the 1912 Geological Survey Memoir (*The Geology of the Lizard and Meneage*, J. S. Flett and J. B. Hill) and the two 1-in. maps dated 1912 and 1934, was humbly to follow the work of my seniors in a part of Cornwall to which I had not previously penetrated, without any idea of criticism; but, although anyone who is conversant with the geology of the Lizard must agree with by far the greater part of the 1912 Memoir, in the course of my very enjoyable trips, during which I had the advantage of discussions with Sir John Flett and Dr. E. M. L. Hendriks, points have cropped up that are new or present problems on which I cannot see eye to eye with the surviving author of the Memoir, who has suggested that I should publish my results before he produces a new edition.

As I have no wish to trespass on the ground covered by Dr. Hendriks in her very fine work on "Rock Succession and Structure in South Cornwall" published in the *Quarterly Journal of the Geological Society* for 1937 (xciii, 322–367), I shall confine myself to the so-called "Lizard Boundary" and the country to the south of it; and in referring to the sedimentary rocks to the north I propose to use that familiar and non-committal Cornish word "killas". In my contribution to the discussion on Dr. Hendriks's paper (op. cit., pp. 361, 362) I referred briefly to what has always been to me a geological comedy in connection with the two Survey maps, Newquay (346) and Falmouth (352), when I, mapping the southern part of the Newquay sheet under the supervision of Clement Reid, the District Geologist, had to join up with J. B. Hill, who was mapping the Falmouth sheet. Why, in 1906 when both these maps were published, the same beds should have been called Ladock Beds on the Newquay sheet and Grampound Beds on the Falmouth sheet, although placing the two sheets in juxtaposition shows they are continuous, I do not know; but there was no doubt in my mind in 1903 that the Ladock Beds, the Grampound Beds, the Staddon Grits, and the Portscatho Series of Hill were all the same thing. In 1936 I went over ground familiar to me in 1903 and could not find any reason to revise my old mapping of the beds in the south of the Newquay sheet as continuous with Hill's Portscatho Series; and it is interesting to note that ten years later Upfield Green and C. D. Sherborn wrote in this Magazine (1913, p. 71) concerning the Geological Survey maps: "The one serious error is the line of 'conglomerate' dividing the Grampound Grit and the Portscatho Beds almost at right angles to their strike on sheet 353 (Mevagissey). But as these two deposits are one and the same, this obvious error need not detain us."

I am very much indebted to the Director of the Geological Survey of Great Britain for giving me access to the collection of Lizard rock-sections and to Professor C. E. Tilley for allowing me to work through the collections in the Department of Mineralogy, Cambridge.

THE PORPHYRY-VEINS OF MULLION COVE.

On p. 137 of the Memoir the distribution of "red gneiss" as dykes and irregular tongues on the west coast of the Lizard from Pentreath Beach to Mullion Cove is described briefly and "masses of red or pink gneiss" are mentioned as occurring on the south side of the latter locality (map-reference Ordnance Survey 6 inches to the mile, sheet lxxxiv N.W. and S.W.)

The rocks referred to occur as veins about 4 inches thick in the hornblende-schists of the Lizard Series and are prominent objects in the cliff abutting on the southern pier of the harbour, in the entrance to the cave that leads from the harbour to the small beach on the south, and in a cave opening on that beach. The rock composing these veins is very fine grained, containing a few phenocrysts of felspar not easy to see in a hand-specimen and not exceeding a millimetre in greatest dimension, and not showing good crystal outline in sections. They seem to be chiefly orthoclase. The mass of the rock consists of minute grains of felspar, some showing polysynthetic twinning, orientated in the direction of flow, shreds of biotite also showing the effect of flow, garnet in minute pink crystals and calcite as veins and also disseminated through the rock. The refractive index of the felspar is generally lower than that of the balsam used for mounting and can therefore be taken to be orthoclase and albite. In none of the eight slides prepared from specimens collected by myself and from supplementary specimens kindly sent to me by Dr. Hendriks, can I prove the presence of any quartz.

The most interesting, however, of these fine-grained vein-rocks, which may be called porphyry-veins showing faint flow structure, is that in the cliff abutting on the southern pier of the harbour; because in addition to felspar, biotite, and garnet, the two sections prepared both show conspicuous but not very well formed prisms of blue-green tourmaline. In the Memoir (p. 137) it is assumed that these red vein-rocks are part of the acid portion of the Kennack Gneisses; but the tourmaline in this Mullion Harbour rock, with the exception of the datolite found by Mr. W. F. P. McLintock at Ogo Dour, on the same 6 in sheet (*Mineralogical Magazine*, xv, 1910, 407), is the first pneumatolytic mineral found south of the "Lizard Boundary", as far as I can tell from the literature and from an examination of the many slides in the Geological Survey and Sedgwick Museum collections.[1]

I am, however, permitted by the Director of the Geological Survey to mention a rock of great interest in his collection that came from the breccia of the Boundary Fault in Polurrian Cove (Ordnance Survey 6 inches to the mile, sheet lxxx S.W.), but which is not referred to in the Memoir. This is an aplite with much topaz (5336) and associated with pegmatite in the hand-specimen. No. 5336 A is a purple fault-breccia from the same locality as the topaz-aplite. The breccia I found on the beach without much trouble: it is clearly part of the Boundary Fault breccia; but I have failed so far to find the topaz-aplite and pegmatite, which I suspect are only exposed after the sand has been temporarily scoured away from the beach by a storm. There is no doubt, however, that this topaz-aplite occurs not far from the tourmaline-bearing vein in Mullion Harbour, but I will refrain at present from speculating on their bearing on the geology of the district.

Among the vegetation on the top of the cliff between Mullion Cove and Ryniau (see 6 in. map) Dr. Hendriks showed me in 1937 some blocks of pegmatite with which, on clearing away some soil, we found a fine-grained rock resembling an aplite, but a slide showed it to be microgranite with small amounts of biotite and muscovite and without a trace of tourmaline or topaz. Near by at Ryniau is a large acid vein extending from the top of the cliff to the shore. This Dr. Hendriks has described as aplite with cordierite-sillimanite-gneiss on its west margin (*Trans. Roy. Geol. Soc. Cornwall*, vol. xiv, pt. vii, 1936). I have only seen the upper part of this vein from which a specimen proved to be granite-porphyry with abundant biotite and faint flow structure.

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[1] Since this was written Mr. E. H. Davison has pointed out to me a reference in his *Handbook of Cornish Geology* (2nd. ed., p. 23) to tourmaline in pegmatite cutting Kennack granite at the 6th mile from Helston on the Lizard road. The author, who obtained a specimen without difficulty, regrets having missed this reference.

Although the red colour and the faint flow structure suggest that the Mullion Cove porphyry-veins are derived from the same source as the acid portion of the Kennack Gneisses, that relationship is by no means established. The abundant garnets, the apparent absence of quartz, and the tourmaline in the one vein do not fit with the Kennack rocks.

A LENTICLE IN SERPENTINE.

In 1936 Dr. Hendriks sent me some specimens from a hard, fine grained lenticle that she had found in serpentine a short distance south of Mullion Harbour. This lenticle is difficult of access except in the very calmest weather and I have only seen it from the top of the cliff; but Dr. Hendriks tells me it measures 8 feet by 3 feet and lies across the jointing of the serpentine. Six slides prepared from the specimens show a remarkable rock. In the hand-specimens it is partly purple and partly grey. Slides show that the purple colour is due to the presence of small ragged prisms with extinction angles varying from 33° to 48°, In one slide this mineral has been almost entirely replaced by chlorite and a black opaque mineral. Although no characteristic basal sections are visible there is little doubt that the mineral is a pyroxene. In three slides there are bodies which without crossed nicols resemble kaolinized felspar, but they are almost isotropic and have chlorite associated with them. Their nature is unknown. But for these bodies the whole rock is very fine grained and has to be studied under a high power, which shows that it is composed of the pyroxene, chlorite, prehnite, sphene, and very minute garnets with hexagonal and quadratic outline. Opaque black grains are abundant. The prehnite occurs as irregular plates disseminated through the rock and as veins. There is no calcite and not a trace of felspar.

Fortunately light was thrown on the nature of this lenticle by a vein which Dr. Hendriks and myself saw some way down the cliff at Parc Bean, near Predannack Wallas Farm, and not far from sea-level, where there are two small patches of serpentine in the hornblende-schists and where the evidence of *lit-par-lit* injection of the former into the latter is very good. In one of these patches of serpentine is a much decomposed "black dyke" dipping east and well exposed on the cliff close to a junction of serpentine with hornblende-schist. It is mostly soft, but contains lenticles of hard grey stone, the largest seen being 8 feet by 2 feet. A specimen from a smaller lenticle shows a mass of mostly isotropic material, probably chlorite, and ragged areas of doubly refracting mineral with some of the characteristics of prehnite, but the rock is too fine in grain to make dogmatic statements about it. The general resemblance to the Mullion lenticle is, however, striking, and I have no doubt that the latter is part of a black dyke, originally dolerite, that has been decomposed and has one hard lenticle showing on the cliff-face. On p. 111 of the Memoir a black dyke trending N.W. and traversing serpentine and hornblende-schist is mentioned at Ogo Dour, close to Parc Bean, but it is not so much altered as the dyke just described. On p. 115 the action of solutions that percolated through the serpentine on the basic dykes is mentioned, but these cases at Parc Bean and Mullion are extreme examples and show that when the dykes were intruded into the serpentine the latter, or its parent rock, must have been still very hot and capable of producing profound metamorphism in the intruded rocks, the abundant prehnite representing the original lime-felspar.

Carboniferous Palaeoniscids from Northumberland and Berwickshire.

By J. A. Moy-Thomas, Dept. of Zoology and Comparative Anatomy, Oxford.

(PLATE XII.)

Introduction.

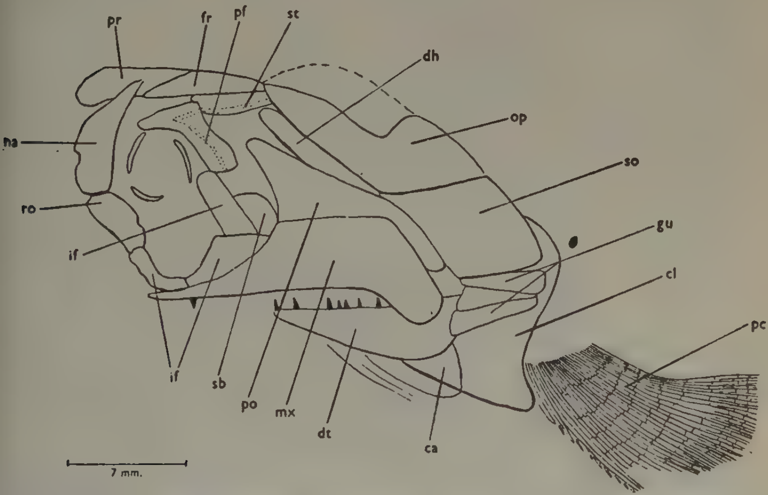
My attention was drawn by Dr. E. I. White, of the British Museum (Natural History), to a small collection of fossil fishes in the Geological Survey from the Cementstones of the Lower Carboniferous of Coomsdon Burn, Redewater, Northumberland. These fishes, which were collected by the late Mr. John Rhodes, are mainly Palaeoniscids, but there are also a few *Rhizodus* scales and a Helodont tooth. The Palaeoniscids had previously been referred by Miller (1887) to species characteristic of the geologically younger Calciferous Sandstone of Glencartholm, Eskdale, Dumfriesshire. These identifications are, however, incorrect, and the interest of the fauna lies in its close resemblance to that of Foulden in Berwickshire described by White (1927). As the two faunas are practically identical, Dr. White suggested to me, that at the same time as I described these new fishes, I might add to some of his original descriptions of the Foulden fishes in the light of additional material from the collections of the late Mr. T. M. Ovens now in the British Museum (Natural History) and of the late Mr. John Smith now in the Geological Survey. The following is an account of the Coomsdon Burn Palaeoniscids with further notes on those of Foulden and a comparison with those of other Cementstone localities from the border counties.

I would like to express my gratitude to Dr. White for suggesting this work and for the loan of the fishes in the British Museum (Natural History), and to Drs. C. J. Stubblefield and F. W. Anderson for the loan of those in the Geological Survey. I would also like to thank Professor E. S. Goodrich for reading and criticizing this manuscript.

GENUS **Styracopterus** Traquair.

Styracopterus ottadinicus (White).

There is a single rather small specimen of this fish (R1537–8 G.S.)[1] from Coomsdon Burn previously attributed to *Holurus parki*. Although many new specimens of this species have been found at Foulden since White's original description, I am unable to add further to it.



TEXT-FIG. 1.—*Strepheoschema fouldenensis* White. The head and pectoral fin of P14552 B.M.N.H.

GENUS **Strepheoschema** White.

Strepheoschema fouldenensis White. (Text.-fig. 1.)

There is one very poorly preserved specimen of this fish (R1539 G.S.) from Coomsdon Burn, previously attributed to *Rhadinichthys elegantulus*. Although the state of preservation is bad, the ornament of the scales and mandible, and the nature of the pectoral and caudal fins leaves no doubt of the correctness of the identification of this specimen.

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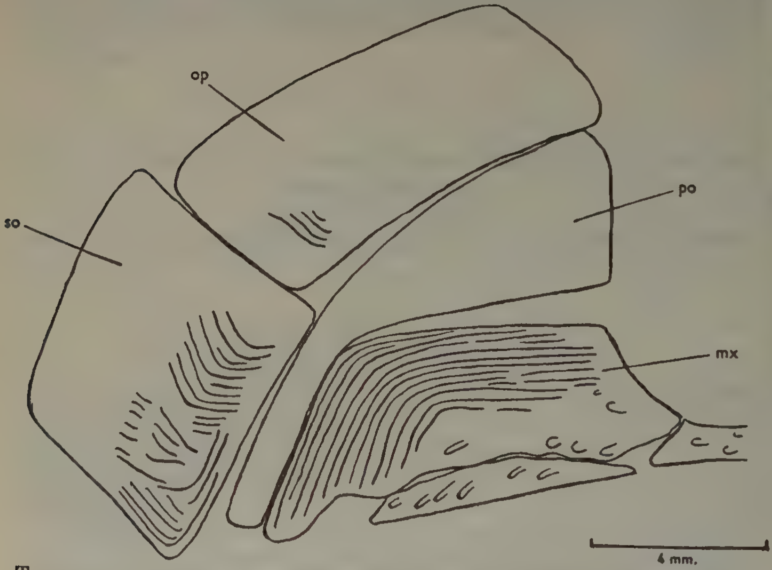
[1] The letters G.S. and B.M.N.H. used throughout this paper denote that the specimens belong either to the Geological Survey or to the British Museum (Natural History) respectively.

A new and well-preserved specimen (P14552 B.M.N.H.) from Foulden, showing the head and anterior part of the trunk, makes it possible to add to the original description. This specimen (text-fig. 1) shows the following new bones in the head: two infraorbitals, a suborbital, the subopercular, supratemporal, postfrontal, and nasal. These bones are ornamented with irregular longitudinal striae, which are much interrupted and anastomose frequently, except the subopercular on which there are a few widely spaced striae running mainly parallel with the dorsal and ventral margins. The pectoral fin, previously unknown, is well shown. As White forecasted, it is rather large and fan-shaped, consisting of about thirty lepidotrichia, of which the sixth seems to have been the longest.



Text-fig. 2.—*Strepheoschema rhodesi*, sp. nov. Opercular apparatus and maxillary of R1724 G.S.

The anterior lepidotrichia are stout and unjointed, their ends alternating with well-formed fulcral scales. The more posterior lepidotrichia are fairly distantly articulated to their bases and bifurcate distally.

Strepheoschema rhodesi sp. nov. (Plate XII, fig. A, text-figs. 2, 3.)
Holotype.—R1664 G.S.

Paratypes.—R1724 G.S., R1725–6 G.S., R1759–60 G.S.
Locality.—Coomsdon Burn, Redewater, Northumberland.

Specific diagnosis.—Fishes not known to exceed 14 cm. in total length, the length of the head being contained probably about 4½ times and the greatest depth of the body about 3½ times in the total body length. The body deeply fusiform. The body scales not denticulated posteriorly, and only ornamented with a few fine grooves on the anterior part of the body, the posterior scales smooth.

Description.

The skull.—The head is only preserved in R1724 G.S. (text-fig. 2). The suspensorium is oblique, and the subopercular about two-thirds the length of the opercular. Only the expanded part of the maxillary is visible and this is of the normal rectangular shape of Palaeoniscids. Only the posterior part of the skull roof is visible, but it is not possible to determine the sutures of the individual bones.

The expanded part of the maxillary is ornamented with striae running parallel with posterior and dorsal margins, and ventrally with tubercles. The ornament of the subopercular consists of widely spaced striae running more or less transversely, and that of the opercular is also of striae but is only preserved in a small patch. The roofing bones are ornamented with longitudinal striae which anastomose and are occasionally interrupted.

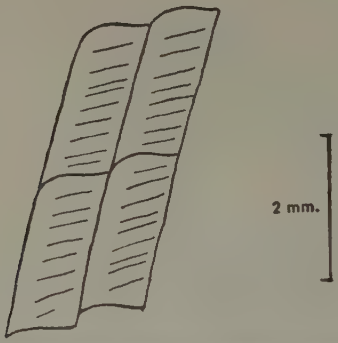
The paired fins and their girdles.—Nothing is known of the paired fins, and of the girdles the supracleithrum is alone very poorly preserved in R1724 G.S.; it is ornamented with longitudinal striae.

The unpaired fins.—The unpaired fins are well shown in the holotype (Pl. XII, fig. A), and are situated rather far back and nearly opposite one another. The dorsal and anal fins are triangular and acuminate, consisting of about thirty-five frequently articulated, distally bifurcating lepidotrichs, of which the seventh is the longest. The fins have well-formed fulcra on their anterior margins. In R1759–60 G.S. remains of the axonosts and baseosts of the dorsal and the baseosts of the anal fins are visible. The caudal fin, well shown in the holotype, is heterocercal, inequilobate, and fairly deeply cleft with a long slender axial lobe. The anterior margin of the hypochordal lobe bears fulcra, but unfortunately most of the anterior lepidotrichia are displaced. All the rays dichotomize distally.

The axial skeleton.—The haemal arches of the posterior part of the body and caudal regions are visible in R1759 G.S. These are of the usual type found in palaeoniscids with long thin haemal spines, which become broadened in the caudal region.

The squamation.—The scales (text-fig. 3) are rhomboidal, those of the anterior flank more than twice as deep as broad. The scales gradually decrease in size posteriorly and the depth and breadth becomes more equal posteriorly. The scales are not denticulated posteriorly and are ornamented with a few widely spaced, fine antero-posterior grooves. Posteriorly on the body and on the axial lobe of the tail the scales are smooth. Above the anal fin the scale rows turn forward and the scales are small. There are traces of smaller scales beneath the dorsal fin, but this region is only preserved in the holotype and is very much disturbed. There are some ridge scales in front of the dorsal fin, but it is not possible to determine how far forward they were continued. The ridge scales of the axial lobe of the tail begin almost immediately behind the dorsal fin. There are also traces of ridge scales between the anal and caudal fins.

Remarks.—These specimens had previously been attributed to *Canobius ramsayi.* They are, however, particularly interesting in being the only species found at Coomsdon Burn, which is not also found at Foulden. This species can easily be distinguished from *Strepheoschema fouldenensis* by the ornament and undenticulated posterior margin of the scales. The great depth of the body, the nature of the head bones, and the small scales beneath the dorsal and above the anal fins leave no doubt that it is rightly attributed to *Strepheoschema.* The specific name is in memory of Mr. J. Rhodes who collected the specimens.



Text-fig. 3.—*Strepheoschema rhodesi* sp. nov. Anterior flank scales.

Genus **Aetheretmon** White.

Aetheretmon valentiacum White.

There are three small specimens of this fish from Coomsdon Burn, R1557–8 G.S., R1562–3 G.S., R1727 G.S., which had previously been referred to *Rhadinichthys elegantulus.*

Aetheretmon valentiacum var. *ovensi* White.

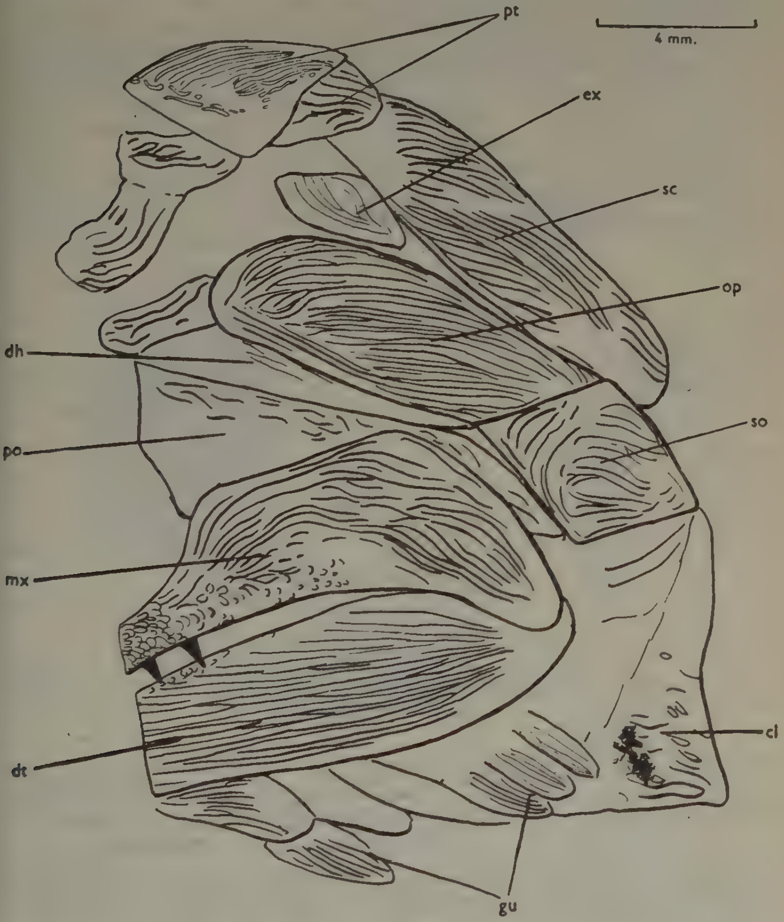
There is a single specimen of this variety from Coomsdon Burn, previously identified as *Rhadinichthys elegantulus.*

None of these specimens nor the few new ones from Foulden provide any further knowledge of the anatomy of this species.

Aetheretmon whitei sp. nov. (Plate XII, fig. B, text-figs. 4–6.)

Holotype.—P14566 B.M.N.H.

Description of Varieties.—There are only two specimens of this fish, one, the holotype, from Foulden, the other from Coomsdon Burn. I would have had no hesitation in describing these specimens as two species had not White (1927) shown that *Aetheretmon valentiacum* was divisible into two varieties, differing in much the same respects as these two specimens do from one another. I have, therefore, considered the Coomsdon Burn specimen to be a variety of the same species as the Foulden specimen.



TEXT-FIG. 4.—*Aetheretmon whitei* sp. nov. Head of type specimen. P14566 B.M.N.H.

Specific diagnosis.—Fishes not known to exceed 9 cm. in total length; the body elongate fusiform, the head large, contained about 3½ times and the greatest depth of the body about 4 times in the total body length. The scales not denticulated posteriorly.

Diagnoses of varieties.

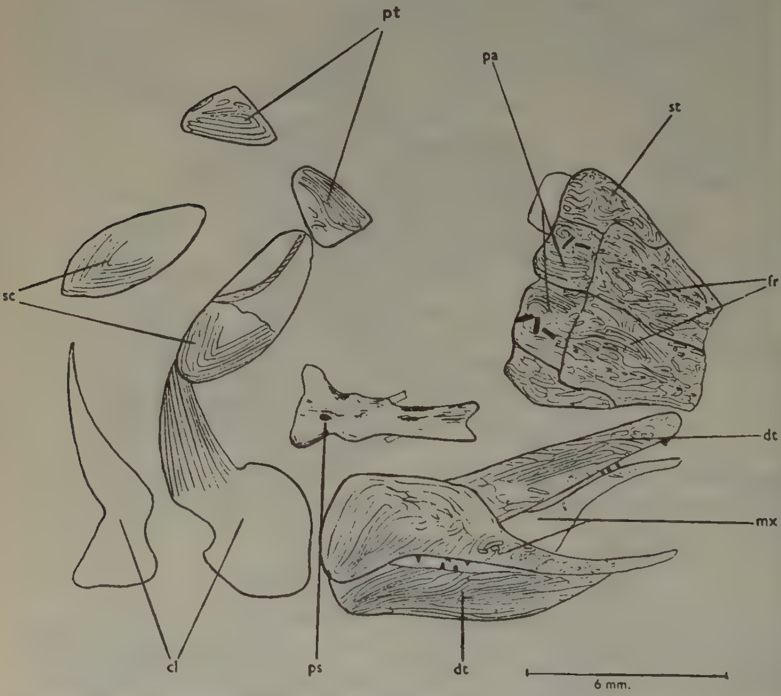
Aetheretmon whitei forma typica. Scales with numerous rugae, which may coalesce posteriorly.

Aetheretmon whitei var. *rhodesi* nov.

Holotype of variety.—R1555–6 G.S. Scales with fewer rugae never coalescing posteriorly.

Description.

The skull.—All that is known of the head is shown in text-figs. 4, 5. The dermal roofing-bones are ornamented with elongated tubercles and ridges running mainly antero-posteriorly. The operculum, suboperculum, and gulars have numerous rugae which are more or less parallel with the long axes of the bones; the little that can be seen of these bones in var. *rhodesi* leads me to suppose that the rugae were less numerous. The rugae of the mandible are in two rows, the lower running more or less parallel with the basal margin and the upper meeting the dorsal margin at an oblique angle. There is a small parasphenoid in R1555–6 G.S. The maxillary and dentary teeth are conical and not very large.

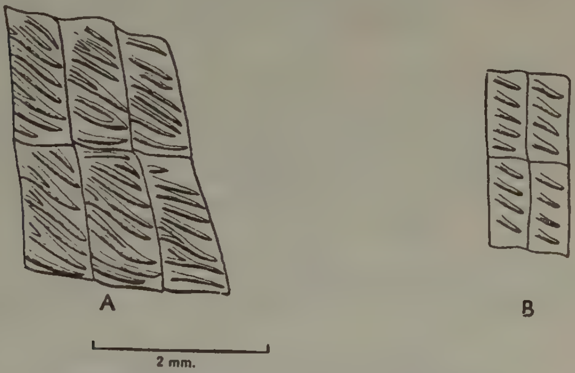


Text-fig 5.—*Aetheretmon whitei* var. *rhodesi* nov. Head of type of variety. R1555 G.S.

The paired fins and their girdles.—Neither of the paired fins is preserved. The cleithrum and supra cleithrum are longitudinally striated, and the clavicles (P14566 B.M.N.H.) are tuberculated.

The unpaired fins.—Neither the dorsal nor the anal fin is at all well preserved in either specimen. It can, however, be said that they were situated far back and opposite one another. The caudal fin, only seen in the holotype, is too poorly preserved for description.

The squamation.—The scales (text-fig. 6) are rhomboidal, not denticulated posteriorly, and ornamented with diagonal ridges very similar to those of *Aetheretmon valentiacum.* On the flank scale of the forma typica these ridges are fairly numerous, as many as eight or nine, which may coalesce posteriorly, whereas in the variety *rhodesi* they are never more than five, not coalescing posteriorly. In front of the dorsal fin the row of ridge scales characteristic of the genus is present.



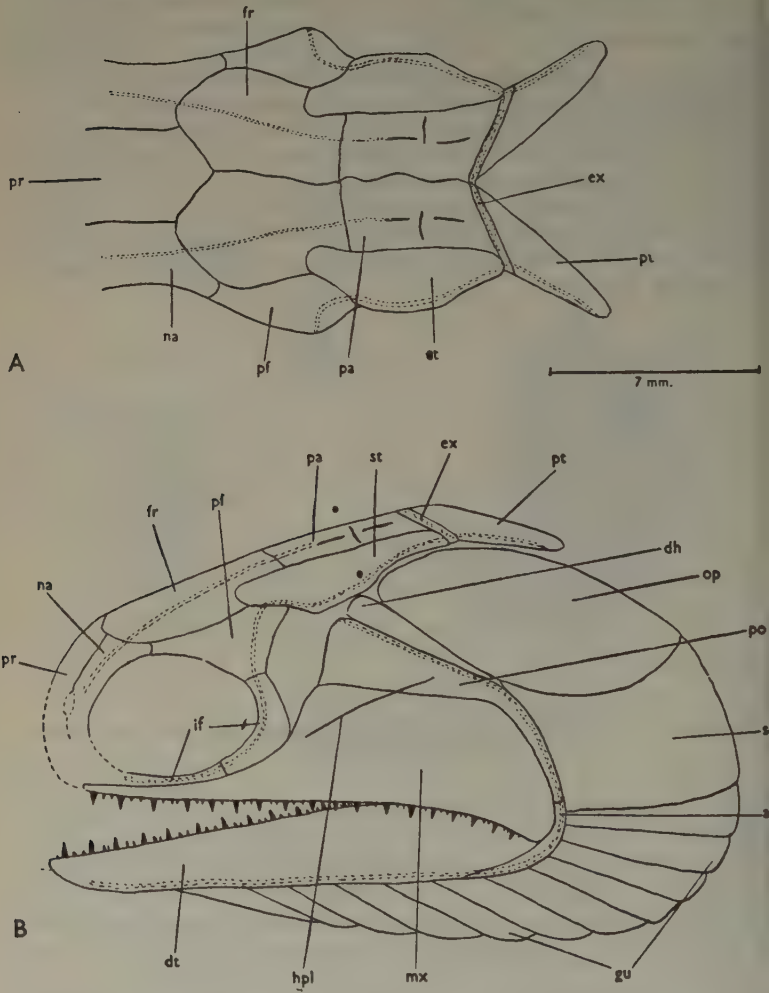
Text-fig. 6.—*Aetheretmon whitei* sp. nov. A, flank scales of the forma typica, and B, of var. *rhodesi.*

Remarks.—The Coomsdon Burn specimen of this fish had previously been attributed to *Holurus parki.* The nature of the scale ornament and dorsal ridge scales leaves little doubt that this fish is rightly considered to be a new species of *Aetheretmon.* The absence of posterior denticulations to the scales distinguishes it from *A. valentiacum.* The species is named in honour of Dr. E. I. White.

Genus **Carboveles** White.

Carboveles ovensi White. (Text-fig. 7.)

This fish has not been found at Coomsdon Burn. Since, however, six new specimens from Foulden have come to hand, it is possible to supplement White's description of the head. The arrangement and shape of the bones and the course of the sensory canals as far as can be determined are shown in text-fig. 7. The most characteristic features are the rather long parietals and short frontals and large size of the postfrontal. The horizontal pit-line of the cheek can be seen running across the top of the maxillary and the preopercular.



Text-fig. 7.—*Carboveles ovensi* White. Restoration of head, A in dorsal, and B in ventral view.

COMPARISON OF THE PALAEONISCIDS OF OTHER CEMENTSTONE LOCALITIES IN THE BORDER COUNTIES WITH THOSE OF COOMSDON BURN AND FOULDEN.

(1) *Tarras Foot, Eskdale, Dumfriesshire.*

There are two Palaeoniscids from this locality, *Styracopterus fulcratus* and *Rhadinichthys laevis* (Traquair 1881, Moy-Thomas 1937). The former is very closely related to *Styracopterus ottadinicus*. The latter appears to be generically distinct from *Aetheretmon*. Unfortunately it is only known from a single specimen, but the deeply cleft tail and absence of a long row of dorsal ridge scales seems to justify its inclusion in the genus *Rhadinichthys*.

(2) *River Tweed, below Coldstream Bridge, Berwickshire.*

The small fish *Styracopterus ischipterus* (Traquair 1881, Moy-Thomas 1937) from this locality is a juvenile form, and very difficult to distinguish from *S. ottadinicus*. Further fossils from this locality will probably show them to be synonymous.

(3) *Blackadder Water, near Duns, Berwickshire.*

The small fish from this locality named "*Canobius obscurus*" by Traquair (1881) has been shown to be almost certainly a species of *Aetheretmon* (Moy-Thomas 1938). The unsatisfactory nature of the remains makes specific identification impossible.

SUMMARY.

The following faunal list provides a comparative summary of the Palaeoniscids of the chief Border Cementstone localities :—

Foulden.
Styracopterus ottadinicus (White).
Carboveles ovensi White
Aetheretmon valentiacum White
Aetheretmon valentiacum var. *ovensi* White.
Aetheretmon whitei sp. nov.
Strepheoschema fouldenensis White.

Coomsdon Burn.
Styracopterus ottadinicus (White).
Aetheretmon valentiacum White.
Aetheretmon valentiacum var. *ovensi* White.
Aetheretmon whitei var. *rhodesi* nov.
Strepheoschema fouldenensis White.
Strepheoschema rhodesi sp. nov.

Tarras Foot.
Styracopterus fulcratus Traquair.
Rhadinichthys laevis Traquair.

Coldstream.
Styracopterus ischipterus (Traquair).

Blackadder Water.
Aetheretmon sp. (" *Canobius obscurus* ").

EXPLANATION OF LETTERING OF TEXT-FIGURES.

ag = angular.
ca = clavicle.
cl = cleithrum.
dh = dermohyal.
dt = dentary.
ex = extrascapular.
fr = frontal.
gu = gular.
hpl = horizontal pit line.
if = infraorbital.
mx = maxillary.
na = nasal.
op = opercular.
pa = parietal.
pc = pectoral fin.
pf = postfrontal (dermosphenotic).
po = preopercular.
pr = postrostral.
ps = parasphenoid.
pt = posttemporal.
ro = rostral.
sb = suborbital.
sc = supracleithrum.
so = subopercular.
st = supratemporal.

EXPLANATION OF PLATE XII.

Fig. A. *Strepheoschema rhodesi* sp. nov. The type specimen R1664 G.S. × 1⅙.
Fig. B. *Aetheretmon whitei* sp. nov. The type specimen P14566 B.M.N.H. × 1½.

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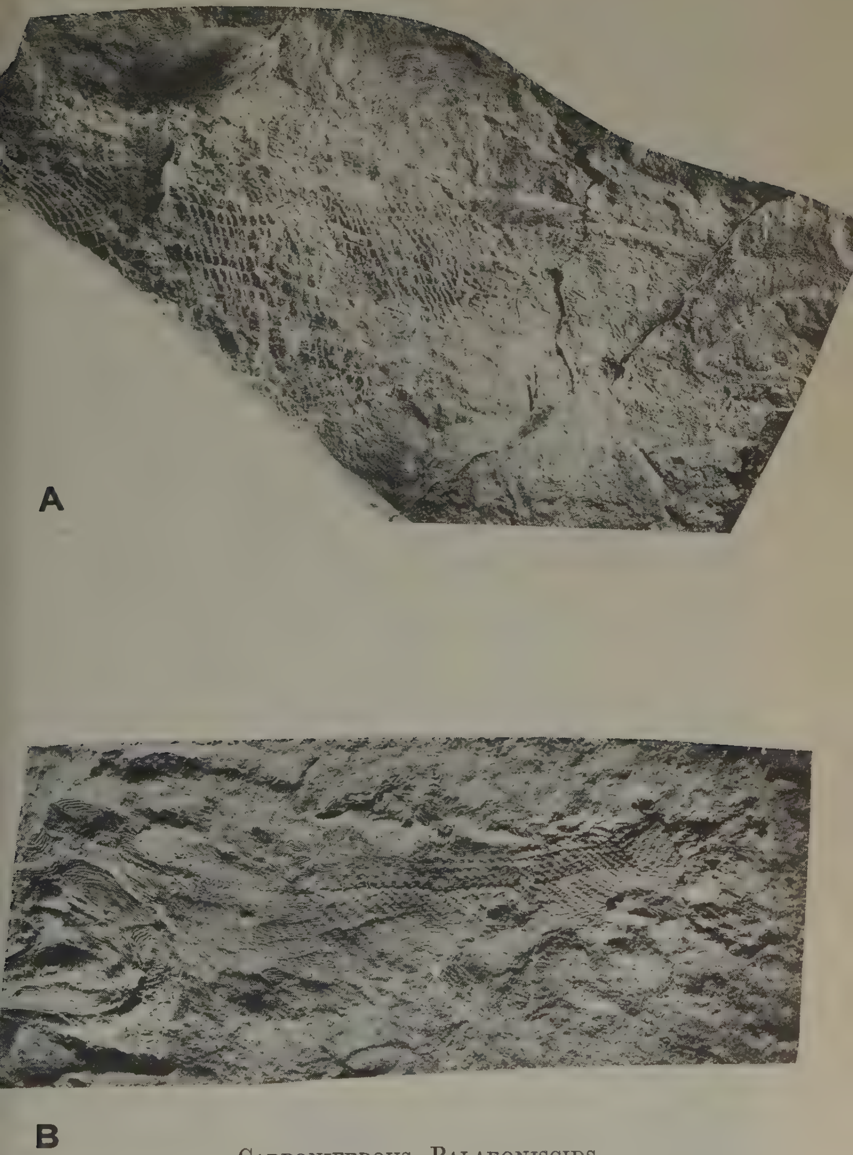
ERRATUM.

F. R. S. Henson. "Stratigraphical Correlation by Small Foraminifera in Palestine and Adjoining Countries". Vol. lxxv, No. 887, May, 1938.

p. 231, line 24, for *typical*, read *atypical*.



CARBONIFEROUS PALAEONISCIDS.

[*Facing p.* 318.

REVIEWS.

Our Wandering Continents: An Hypothesis of Continental Drifting. By Alex L. du Toit. pp. xiii + 366, with 48 figures. Edinburgh: Oliver and Boyd, 1937. Price 18*s*.

IN this book, dedicated to the memory of Alfred Wegener, Dr. du Toit states the case for Wandering versus Permanent or Semi-permanent Continents and, as a special pleader, he endeavours to make plain to the jury that his opponents are diehards who refuse to see the light or accept the obvious. The publication of *Our Wandering Continents* is an event of great importance: the author is exceptionally well qualified by his own researches into the geological structure and palaeontology of South America and South Africa to speak with authority. No geologist has done more than Dr. du Toit to search for definite evidence in support of the former union of continents now separated by wide stretches of oceanic waters; and he has been conspicuously successful. He has now undertaken a critical revision of geological principles as well as a review of the geology of the whole earth, a truly ambitious undertaking which demands not only acquaintance with an extensive literature on diverse subjects but also the ability to visualize from many different angles the changing face of the earth. His aim is to present a world-picture of successive revolutions; the correlation and synthesis of evidence derived from a study of earth-movements, the distribution of animal and plant life in successive periods; consideration of the bearing of palaeontological data on the problem of climatic zones, and to follow many other lines of inquiry. The question is: how far has the author been successful? He has accumulated an enormous mass of information which, despite lack of coherence, will be of great value to readers who desire to follow the devious trails blazed by many adventurers and to study in true perspective the bearing of conflicting hypotheses and the formidable array of facts upon one of the most baffling and fascinating problems of earth-history. Readers are assisted by a useful glossary which might have been still more helpful if Greek and Latin derivations had been given. The author, with the best intentions, has not succeeded in producing a book that can be read and understood with reasonable ease. The reviewer has the highest admiration of Dr. du Toit's ability and enviable familiarity with the contributions of authors interested in a bewildering variety of subjects; he is also definitely in sympathy with the hypothesis usually associated with the name of Wegener, and he frankly admits that some of the difficulty he has experienced in piecing together the several sections of the volume into a connected whole are due to his own ignorance. The impression left after reading the book is that the author might have presented a more convincing case had he devoted a larger proportion of space to general summaries, written in a form intelligible to the layman. In short one feels that Dr. du Toit has yielded to the temptation of using the contents of note-books as separate entities, leaving readers to make their own synthesis, instead of co-ordinating the results of his amazingly laborious researches, and presenting his considered opinions in a series of essays. This criticism is made by one who shares many of the author's views and in the hope that the great service already rendered may be made still greater and more effective by a less controversial presentation in simpler language.

A general idea of the scope of the book, and incidentally the method of treatment, may best be given by brief references to the chapters. In Chapter I current theories are contrasted with the "New Geology". Despite the different opinions held by the orthodox there is general agreement that the mechanism involved in continental drift is too colossal to be seriously entertained. If, on the other hand, geologists would take a broader and holistic view they would be driven to share the author's conviction that a world without some form of Continental drift is "as unreal as one lacking in biological evolution". He concludes his confident statements on the gospel of Drift by enumerating several curious facts "ordinarily only explainable in a rather nebulous fashion, which find their ready solution under our hypothesis". The author's enthusiasm and a faith justified by personal observation may almost persuade the formidable array of doubters to admit the possibility of wandering continents. In Chapter II he gives a very useful sketch of the evolution of ideas on Continental drift. The first "definite and convincing presentation came from F. B. Taylor in 1908". Wegener's belief in a shifting of the polar axis is not shared by du Toit: it is, however, very difficult to harmonize this comforting opinion with references to the position of the poles in later chapters. In writing on Isostasy in Chapter III the author expresses the view that the ocean floors do not, as often asserted, consist entirely of dense sima: the upper part even of the Pacific deeps must contain "a certain thickness of sial, probably materials of intermediate or even acid composition, the presence of which is definitely indicated from seismic and other evidence". He holds that "Isostatic compensation is a most powerful agent in the dynamic evolution of the earth". He draws attention to certain changes made by Wegener in the fourth edition of *Die Entstehung der Kontinente*, notably his substitution of the submerged continental shelves for the present coast-lines in fitting together land-masses. Chapters IV and V, devoted to Gondwana Land, are especially valuable chiefly because the author is pre-eminently qualified to speak with assurance based on first-hand knowledge. There must surely be not a few who accept the author's conclusion that "the marvellous parallelism shown by the stratigraphies and tectonics of South America, South Africa, and Australia . . . indicate an enormously high probability that the phenomena in question were due to the same controlling orogenic forces operating throughout that lengthy period" (i.e. during the early Mesozoic and the Palaeozoic). Chapter VI, "comparisons between the fragments of Gondwana," contains much information of primary importance in relation to the case for continental drift, but one wishes that Dr. du Toit, after assembling his notes, had written a more readable exposition on the significance and interpretation of the facts. The brief reference to the Kerguelen Archipelago on page 130 might be amplified by an allusion to the occurrence in the Tertiary sedimentary beds of a species of *Araucaria*, the nearest relative of which now lives on Norfolk Island. *Araucaria* and other fossil plants were discovered by Dr. A. de la Ruë in 1931 and described by Seward and Conway in the *Annals of Botany*, 1934. One of the most striking links between Antarctic and South Africa is the occurrence in both of fossil stems of very unusual structure assigned to the Triassic genus *Rhexoxylm*: this piece of evidence might have been given at greater length for the benefit of readers who are not palaeobotanists.

Chapters VII and VIII are devoted to Laurasia. Du Toit says: "This crossing of all the Palaeozoic fold-systems in the North Atlantic region is, precisely like that already described for the South Atlantic, held to form one of the weightiest arguments in favour of the Displacement Hypothesis, though conveniently ignored or strongly disputed by the orthodox school." "Conveniently ignored" might with advantage have been omitted. In the section on the Late Palaeozoic floras a fuller account of the recent work of Professor Halle and other palaeobotanists on the *Gigantopteris* and other floras in the Far East would have enhanced the value of this summary of ancient phytogeography. One of the most remarkable instances of plant distribution and the very close resemblance of floras separated by many degrees of latitude has been contributed by Professor Harris of Reading in a series of admirable papers on the extraordinarily rich flora yielded by the early Jurassic and Rhaetic rocks of East Greenland and its comparison with the contemporary flora of Scania. There is no reference to this work either in the text or in the bibliography: this is a pity as it affords one of the most convincing arguments in favour of some form of terrestrial displacement. Chapter IX summarizes the Tertiary History of the Lands: it is by no means easy reading and there is no adequate summary. An interesting piece of evidence, which it is pardonable to have overlooked, in support of a former union of Siberia and Alaska was recently given by Professor Chaney who recorded the occurrence in St. Lawrence Island in the Behring Strait of the widely distributed early Tertiary Conifer, *Sequoia langsdorffi*. Chapter X on the Oceans, like other chapters, suffers from excessive turgidity, though it makes less demands than some of the others on the mental concentration of the reader. The author's opinion that the orthodox view necessitating foundering of large areas of the Early Tertiary lava-fields of Greenland and North-West Europe is highly improbable will doubtless find many sympathizers. Chapters XI and XII deal with the Paramorphic zone, a term applied to a deep-seated region, normally crystalline and solid, the seat of changes in mineral composition but with chemical composition remaining unchanged. The section on Rift Valleys is very good and easy to follow. Chapter XIII is on " Past Climates and the Poles ". In its attitude towards climatic anomalies revealed by the fossil record " Orthodoxy is indeed endeavouring to defend a wholly untenable position ": this, in the reviewer's opinion, is true. There are several references to the position of the poles in relation to the displacement of lands: the author tells us that in using the terms pole-wandering or polar shift he visualizes a thin and distorting crust creeping over its rigid core that has been rotating upon a *fixed axis* and not a change in the direction of that axis in stellar space. In Chapter XIV du Toit gives a short summary of evidence furnished by animals and plants in favour of the Drift hypothesis and enjoys a fling at the builders of a haphazard network of land-bridges, a network that is " palpably absurd " and based on ideas that are " fundamentally unsound ". The fundamentally important question, to what extent is geodetic evidence favourable to continental drift ? is discussed in Chapter XV. As yet the evidence, though promising, is not conclusive: one may hazard a guess that before many years have passed geophysical data will provide positive results. Chapter XVI on The Pattern of the Earth's Orogenies contains much interesting matter: the author regards all major plications as due to drifting, that is " the moving forward of blocks of sial over a stationary sima, or their transport by currents in the sima itself, or else a combination of both these processes ". His contention is that " within the reassembled lands there has been from the Palaeozoic onwards a *regular clockwise shift* in the orientation of the dominant tectonic zones and of their conjugate branches, where such are present ".

In the final chapter the author grapples with causes of drift. If, he says, an adequate force or combination of forces competent to cause continental sliding were forthcoming a host of doubters would be converted: as it is, he adds, " most geologists regard continental drift as a physical impossibility and with such a conclusion most geophysicists agree." He is inclined to follow Holmes in favouring internal rather than external forces. He rejects the hypothesis that looks to contraction of the earth's interior as the main cause and is inclined to the view that magmatic currents have played an important part as factors conditioning displacement.

In the conclusion he tells us that his aim has been to set forth " in an elementary fashion certain individual ideas of Earth Structure and Evolution ". He has put forward " a provisional attempt to interpret the host of phenomena that do not appear to be adequately, if at all, explained under current theories of geology". What is elementary to Dr. du Toit will not be so regarded by many of his readers. One may criticize his method of presentation, his impatience with obstinate opponents, and his disinclination to admit that even the orthodox are seekers after truth. Truth, it has been said, is the hypothesis which works best. Dr. du Toit has brought together a most impressive collection of facts and has expressed his views in no uncertain language: he has made a notable contribution to knowledge which will not only stimulate geologists, palaeontologists, and others to examine afresh and with new ideas their beliefs and disbeliefs, but will convince a fair proportion of readers that the conception of wandering continents is not mere fancy, but fancy that is just one fact the more.

A. C. SEWARD.

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1. GEOLOGICAL HISTORY OF THE EAST INDIES. By J. H. F. UMBGROVE. Reprinted for private circulation from the *Bulletin of the American Association of Petroleum Geologists*, vol. xxii, No. 1, January, 1938, pp. 1–70.
2. ON THE ORIGIN OF THE PACIFIC MAGMA TYPES IN THE VOLCANIC INNER-ARC OF THE SOENDA MOUNTAIN SYSTEM. By R. W. VAN BEMMELEN. *De Ingenieur in Nederlandsch-Indië.* IV. *Mijnbouw en Geologie. De Mijningenieur.* Vol. iv, No. 1, January, 1938, pp. 1–15.

THESE two papers, written in English by two well-known Dutch geologists of the younger generation, should be very welcome reading to all those who are interested in the geology of the Malay Archipelago and Peninsula. Professor Umbgrove says he was persuaded to write his paper by the chief geologist of the Texas Company (California) and compares it to a succession of cinematograph pictures, though of necessity somewhat vague and discontinuous. This comparison is supported by twelve clear maps showing the distribution of the various formations and of the folding of different periods, together with other text-figures. The paper is of course much condensed, but nevertheless contains a large amount of information including a discussion of the geological connection between Burma, as described by Dr. H. L. Chhibber, and the Malay Archipelago and also a discussion of the origin of cherts with radiolaria in the Archipelago and Peninsula. This is the best summary in English of the geology of the East Indies since the publication of Professor H. A. Brouwer's book in 1925.

Dr. R. W. van Bemmelen, who is a member of the Geological Survey of the Netherlands East Indies, discusses at some length in his paper the genesis of Pacific magma-types in southern Sumatra and Java and decides in favour of magmatization of pre-existing crustal rocks by ascending emanations and hybridization or contamination, rather than differentiation of the parent magma; but the chief value of the paper lies in the description of granite, hornblende-granite, granodiorite, diorite, diorite-porphyrite and gabbrodiorite, with contemporaneous dykes of dacitic and liparitic appearance, that were intruded into Lower and Middle Miocene rocks during an Upper Miocene orogenic phase, one of the most interesting discoveries of the Dutch geologists in the East Indies and one which makes the reviewer inclined to revise his views on the age of some of the igneous rocks in the neighbourhood of Singapore (*vide* p. 47 of *The Geology of Malaya*, 1931). The rocks discussed by Dr. van Bemmelen occur in the Barisan Mountains of southern Sumatra, in Sheet 14 (Bajah) of the geological map of West Java and in the Merawan batholith in the Residency of Besoeki of East Java.

J. B. S.

THE PETROLOGY OF THE SEDIMENTARY ROCKS. By F. H. HATCH and R. H. RASTALL. Third edition, revised by MAURICE BLACK. pp. 383, with 75 text-figures. London: George Allen and Unwin, Ltd. Price 15*s*. net.

THE *Petrology of the Sedimentary Rocks* by F. H. Hatch and R. H. Rastall is probably now well known to geologists all over the world and the newly-published third edition will further increase its reputation. The reviser has done his work so well that we have every reason to characterize it as the best textbook on sedimentary rocks that has yet been written.

Black's work is distinguished by clear and perspicuous form as well as by well weighed content. In all branches attention has been paid to modern investigations and the value of the work has been greatly increased by references to the actual literature and by the rich bibliography. The appended classified bibliography will be of great use to students working on special problems.

In the introductory chapters the author gives us a review of the origin of sedimentary deposits. The principle of continuity is claimed but at the same time it is pointed out that the importance of the different processes of sedimentation has varied enormously through geological time. The influence of climate on sedimentation and of environment on deposition is set forth and an account is given of the sources of sedimentary material and the transportation of this material.

In the special part the sediments are divided according to current principles into fragmental, chemical, organic, pyroclastic, and residual deposits and these larger groups are treated separately. By division into chapters and sub-divisions with convenient headings clearness has been preserved even in the treatment of the details. In some cases the new edition contains wholly new-written chapters, as, for instance, that on the ferriferous sediments. As illustrating the rich contents of the book as well as the way the author has sorted his material some of the headings in that chapter may be quoted :—

FERRIFEROUS DEPOSITS.

- Primary and early diagenetic ironstones : Marine.
  - Sideritic limestones.
  - Chamosite-siderite rocks.
    - Cleveland ironstones.
    - Northampton ironstones.
    - Dogger, etc.
  - Glauconitic rocks.
    - Physical properties of glauconite.
    - Modern glauconitic deposits.
    - Older glauconitic deposits.
    - Origin of glauconite.
  - Greenalite ironstones, etc.
- Primary and early diagenetic ironstones : Fresh water.
  - Bog limonites, etc.

The quoted example shows the free way in which the author has pointed out facts of both practical and theoretical interest. The chapters on carbonaceous deposits, phosphatic deposits, saline deposits, residual deposits, and soils also deserve to be quoted for the same reason.

In various chapters there is given a summary of the petrology of limestones, dolomites, and siliceous deposits as well as of the deposits of modern oceans. Weathering, diagenesis, and some other processes are given special attention.

In an appendix we find an account of the commoner minerals occurring in detrital sediments, evidently intended to facilitate their identification.

Even if the reviewer on some details holds another opinion than the author he is still the first to give the work full recognition.

ASSAR HADDING.

THE SCENERY OF ENGLAND AND WALES. By A. E. TRUEMAN. 351 pages, 112 illustrations. London : Victor Gollancz, Ltd., 1938. Price 7*s*. 6*d*.

THIS little book will be a useful companion on tour to those motorists and cyclists who take an interest in the country through which they pass. It may also help to relieve the tedium of a long railway journey, even though the train will not stop to let its passengers study the view.

It is written primarily from a geological standpoint but not for geologists, and no one need be deterred from reading it because he knows no geology. The necessary geological information is given simply and easily in the explanation of the features noticed. Perhaps some of those who are thus so pleasantly guided over the lower slopes may be induced to scale the less accessible heights of palaeontology, petrology, and stratigraphy.

The plan of the book makes it easy for the tourist to use. Each chapter deals with a particular region or type of country. There is, for instance, a chapter on the Cotswold Stone Belt, there is another on the Weald, another on the Fenland, and so on. The topography of each region is described and there are notes about the characters of the villages and churches so far as these are influenced by the local building materials. Perhaps a little more might have been said about the woods and agriculture, for these have a great effect upon the scenery and are themselves influenced by the geology.

The illustrations are all from pen-and-ink drawings, and include many sketches of the country, and of characteristic villages and churches. They are a welcome change after a surfeit of half-tone blocks, and they do not require a loaded paper, so that the volume is comparatively light.

The author is to be congratulated on a book which is sure to be found interesting by many; and since it is likely to reach a second edition it may be worth while to draw attention to the few misprints noted. On page 47, Egton Low Moor is called Egerton Low Moor; and on page 146 the Stour is called the Stroud. The latter is given correctly in the index, the former is not.

P. L.

Federated Malay States: Report of the Geological Survey Department for 1937. pp. 1–56, with a new edition (1938) of the Geological Map of Malaya. E. S. Willbourn, Director, 1938.

In this report Mr. Willbourn has given a more detailed account of the year's work than in any previous annual report, including contributions from Dr. F. T. Ingham, Mr. J. A. Richardson, and Mr. F. W. Roe. The fact that two-thirds of the report deal with economic subjects shows that the staff is giving due attention to the most important side of its duties. Among the subjects discussed are the production of kaolin, bauxite (12,531 tons from Johore), scheelite, wolfram, iron-ore, manganese, gold, tin, and a new discovery of coal near Tapah. Particularly interesting is Mr. Richardson's account of gold mining in Ulu Pahang, though results are not encouraging, the Raub mines excepted.

The map (12 miles to the inch) is an advance on the 1930 map in that it shows a new outcrop of Tertiary rocks in Johore, and outcrops of serpentine that had not been mapped before, though known to exist. Changes in mapping are the alteration of some Trias outcrops to Carboniferous and *vice versa*. The original mapping was to a large extent perforce lithological and the changes may be justified; but it would perhaps have been better to have delayed them until more of the country had been mapped on a larger scale. There is also a change from hornblende-granite to syenite in Ulu Pahang that is debatable, but neither that nor the changes of Trias and Carboniferous will have any adverse effect on mineral production, which is the main care of this very practical and energetic Geological Survey staff.

J. B. S.

GEOGRAPHISCHE UND GEOLOGISCHE FORSCHUNGEN IN SANTA CATHARINA (BRASILIEN). By REINHARD MAACK. Z. d. Gesell. f. Erdkunde zu Berlin, Ergänzungsheft V. 1937.

IN this communication Dr. Maack presents an account of the geology of Santa Catharina, a province lying between 26°–29° S. and 48°–54° W. The western two-thirds of the province is occupied by lava-capped Gondwana beds which are exposed in a bold escarpment sometimes of the order of 1,200 m. high. These are made up of glacial beds at the base followed by sands and shales with a marine Lower Permian fauna.

Sandstones and shales succeed with the *Glossopteris* assemblage and pass upwards into bituminous shales of mid-Permian age containing *Mesosaurus*. The Upper Permian is made up of red sandstones and clays containing plants and entomostraca. The whole system is about 700 m. thick.

Red sandstones and marls with plant and fish remains below and reptiles above amounting to about 190 m. are assigned to the Trias. Three or four pulses of basic lava ranging from andesite to basalt issued from a group of dykes running N.W.–S.E. and formed a sheet from 20–800 m. thick. Still later an injection occurred of nepheline-syenites with an accompanying suite of eruptive and hypabyssal attendants.

Below the Gondwana beds of the escarpment a series of limestones, quartzites, and shales occur, which are placed in the Silurian on the evidence of sundry annelids. These have suffered folding with axes trending approximately north and south. They lie upon more altered sediments cut by granite and pegmatite and strongly folded with a marked east-north-easterly trend. They are recorded as Algonkian, and overlie and encircle an area of para- and ortho-gneisses.

In this coastal region there is evidence of regional uplift in recent times on account of terraces and of the rapid silting up of the various little harbours along the coast. There are traces of mineralization, manganese being the most abundant mineral. Coal is worked from the Gondwana beds in the south of the province.

The author concludes that the complete harmony between the Gondwana beds of Brazil and of Africa provides strong evidence in favour of Wegener's hypothesis.

J. V. H.

The Genesis of the Jotnian Sediments. By H. von Eckermann. Geol. Fören. Stockholm Förh., lix, 1937, 548–577.

FOLLOWING up his previous work on the origin of the Jotnian sediments, the author shows that the supposition of the pyroclastic origin of some conglomerates is untenable, and endeavours to explain apparent contradictions in the nature of the topography at the time of sedimentation, which was complicated by contemporaneous lava-flows and a certain amount of fine ashes. The study of ripple marks in the finer sediments along with other evidence suggests deposition in shallow water, although the evidence of the direction from which the material was derived is not satisfactory. It appears that the contemporaneous weathering of the land surfaces was partly of arid type and partly indicating a moister climate. Deposition was accompanied by frequent block-faulting of small amplitude. There is no evidence of deep sculpturing of the land, and most of the material was derived from the upper surfaces of the lava-flows and from shallow intrusions associated with them. A similar type of sedimentation continued up to the Silurian.

R. H. R.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

Thursday, 9th June.

(1) "The leaching of granite and other rocks." By Mr. E. H. Davison.

The paper describes experiments devised to determine the solubility of granite and other rocks in aerated distilled water. The water is allowed to drip through the crushed rock and is afterwards evaporated and the residue of dissolved material weighed. The accumulated solubles after 25 leachings is analysed. The results show definite solubility in granite, gabbro, and oolitic limestone.

(2) "Some new and little-known meteorites found in Western Australia." By Dr. E. S. Simpson.

Accounts are given of 14 meteorites (11 siderites, 2 stones, and one seen to fall but not yet found), of which 8 are new, bringing the total number known from Western Australia up to 23. New are Dalgaranga (siderite), Dowerin (siderite), Gundaring (siderite, 248 lb., fell April 6th, 1930, found 1937), Kumerina (siderite, 118 lb., found 1937), Landor (siderite), Mellenbye (stone), Wonyulgunna (siderite, 83½ lb., found 1937), and Yalgoo (stone). Meteorites previously described under the names Youndegin, Mount Stirling, and Mooranoppin are identical in structure and chemical composition, and they have all been found on an area of some 10 square miles close to Pikaring (Penkarring) Rock, 34 miles S.E. of Youndegin.

(3) "Francolite from sedimentary ironstones of the Coal Measures." By Mr. T. Deans, with a chemical analyis by Mr. H. C. G. Vincent.

Francolite occurs in oolitic ironstones from the Yorkshire coalfield as small hexagonal plates showing twinning in six sectors. The optical properties, including anomalous features found in other members of the apatite group, are described. Analysis establishes the formula $(Ca,Sr)_{10}(P,C)_6(F,OH)_2O_{24}$.

(4) "On the atomic arrangement and variability of the members of the montmorillonite group." By Dr. G. Nagelschmidt.

X-ray data for the montmorillonite group are given and discussed. The group is shown to have three end-members, Al_2R (montmorillonite) Fe_2R (nontronite) and Mg_3R (magnesium-beidellite) where R is possibly $Si_4O_{10}(OH)_2$. The number of hydroxyls is not quite certain.

Calculations based on the assumption of a three-layer lattice for these minerals show fairly large isomorphous replacements, which are believed to be essential, and a balance between the negative charges due to the replacements and the exchangeable excess cations. The need for more detailed information on these minerals, especially with regard to their dehydration curves, is pointed out.

(5) "On chamosite and daphnite." By Dr. A. F. Hallimond.

Relatively pure chamosite found in a *Cardinia* shell in the Frodingham Ironstone has the simple ratios $2SiO_2,Al_2O_3,3FeO,nH_2O$. Daphnite from Tolgus Mine differs somewhat from this ratio, belonging to a series extending toward the ordinary chlorites. Neither mineral is represented by the Tschermak formula. X-ray photographs of chamosite are constant in pattern and closely resemble those of cronstedtite. Daphnite and thuringite give patterns identical with those of clinochlore but the spacings are slightly different. The two minerals studied are distinct varieties of chlorite. Chemical analyses are by Mr. C. O. Harvey and X-ray measurements by Mr. F. A. Bannister.

(6) "The identity of zinckenite and keeleyite." By Mr. G. Vaux and Mr. F. A. Bannister.

Zinckenite from Wolfsberg, Harz, and keeleyite from Oruro, Bolivia, were compared by means of single crystal X-ray photographs about the *c* axis, and were found to be identical. No twinning was discovered in zinckenite which was found to be truly hexagonal with *a* 44·06, *c* 8·60Å, space-group $C^6{}_6 = C6_3$ or $C^2{}_6 = C6_3/m$.

(7) "A chemical and optical study of a low-grade actinolitic amphibole from Coronet Peak, Western Otago, New Zealand." By Mr. C. Osborne Hutton.

The chemical analysis and optical constants of an actinolitic amphibole from a low-grade albite-epidote-actinolite-chlorite-calcite-schist are given. It is shown that the maximum ext. angle in the prism-pinacoid zone is not to be obtained on a clinopinacoidal section. Details of a rare amphibole comparable with crossite in its optical properties are also given.

(8) "An X-ray examination of mordenite (ptilolite)." By Messrs. C. Waymouth, P. C. Thornley, and W. H. Taylor.

Specimens of the fibrous zeolite mordenite (ptilolite) have been examined by X-ray methods, and the specific gravity and pyroelectric properties determined. Laue- and oscillation-photographs indicate that the structure possesses orthorhombic symmetry, and the unit cell with axes $a = 18{\cdot}25\text{Å}$, $b = 20{\cdot}35\text{Å}$, $c = 7{\cdot}50\text{Å}$, contains four molecules of composition $(Ca,K_2,Na_2)Al_2Si_{10}O_{24}.7H_2O$. The space group is $D^{17}_{2h} - Cmcm$ or $C^{12}_{2v} - Cmc$; the pyroelectric tests are somewhat inconclusive but indicate that the *c*-axis [001] is probably polar. The structure is probably based on a framework of linked tetrahedra.

CORRESPONDENCE.

THE PURBECK BROKEN BEDS.

Sir,—In a recent paper[1] the origin of the well-known Broken Beds of the Lower Purbeck of Dorset has been ably discussed. Dr. W. J. Arkell presents adequate reasons for rejecting the contemporaneous collapse hypothesis of Osmund Fisher which linked the brecciation with the decay of underlying vegetation, and in claiming a wholly tectonic origin for these curious beds has made out a strong case for the existence of tectonic factors in the determination of their present arrangement. But is his explanation of their brecciation and of their restriction to one horizon adequate? This restriction over 14 miles of outcrop is a very striking fact and, as Dr. Arkell says, "at first sight it is rather surprising that the yield took place in these beds." Is it possible that due significance has not been given to some other factor? I refer particularly to the possible former presence of gypsum (or anhydrite) at this horizon and to the effects which the hydration of interbedded anhydrite and the solution of gypsum could have had on these thinly laminated sandy limestones (note the lithology).

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[1] Arkell, W. J., "Three Tectonic Problems of the Lulworth District: Studies on the Middle Limb of the Purbeck Fold," *Quart. Journ. Geol. Soc.*, xciv, 1938, 1–54.

Recently in preparing a new edition (in collaboration with Dr. R. L. Sherlock) of the Survey Memoir on Gypsum and Anhydrite I had occasion to consider the gypsum-anhydrite occurrences in the Lower Purbeck of Southern England. As is well known, gypsum occurs at or near the base of the Lower Purbeck in Kent and Sussex in the form of massive beds, as nodular masses, and disseminated in shales, and is associated with *finely laminated sandy limestones* and cement-stones. It is worked on a considerable scale at the Sub-Wealden Mine near Robertsbridge in Sussex and has been recorded from deep borings for coal at Penshurst, Pluckley and near Battle. Significant features of the records of these borings are the frequent reference to extensive slickensiding in the shales and clays of the Purbecks (and to a less extent in the overlying Wealden) and to the occurrence of brecciated, and crumpled and broken beds of limestone at or above the gypsiferous horizon.

In the memoir dealing with the strata proved in these borings[1] it is stated on p. 72 that "The local crumpling with partial brecciation of the bedding-planes, noted in the Lower Wealden strata, was often still more strongly marked in the Purbecks, increasing in intensity downwards until its maximum was reached in the gypsiferous beds forming the base of the Purbecks."

It seems highly probable that these disturbances are due, as the authors of the memoir thought,[2] to changes in the gypsiferous beds, and here I would include the hydration of anhydrite as well as the solution and redeposition of gypsum.

We must, however, turn to areas where the calcium sulphates have been dissolved for a true appreciation of the effects that can be produced. Among the variety of breccias at the outcrop of the Magnesian Limestones of Durham there are excellent examples of brecciation believed to be due to internal rearrangement associated with the hydration of anhydrite and the solution of gypsum[3] that were formerly present and are known to occur in the limestone at depth. Here, it may be noted, Professors Hickling and Holmes consider the breccias to have been derived "from a *thin-bedded or laminated and fine grained deposit* (the italics are mine) the fragmentation of which appears has taken place in situ" and they regard a deposit consisting of alternating laminae of dolomite and anhydrite as the possible original deposit.

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[1] Lamplugh, G. W., and Kitchin, F. L., "On the Mesozoic Rocks in some of the Coal Explorations in Kent," *Mem. Geol. Surv.*, 1911.

[2] Op. cit., p. 74.

[3] Hickling, G., and Holmes, A., "The Brecciation of the Permian Rocks," *Proc. Geol. Assoc.*, xlii, 1931, 252–5.

H. B. Woodward, though advocating the tectonic rather than the collapse theory for origin for the Broken Beds, notes[1] that "In sandy limestones or calcareous sandstones belonging to the Northampton Sand, a somewhat similar appearance [to the Broken Beds] has been locally produced by the removal of calcareous matter by carbonated water. In this way some of the overlying strata have lost support and become 'Broken Beds'".

In the Lower Purbecks of Dorset large botryoidal masses of gypsum in the marls some distance above the Broken Beds were formerly worked at Durlston Bay. Indications of the former existence of salines are found in the records of salt pseudomorphs and possibly also in the presence of hard "brecciated limestone" above the gypsum horizon in Durlston Bay, and the occurrence of honeycomb limestone.[2]

Recent deep borings at Portsdown and Henfield have proved considerable beds of anhydrite in the Lower Purbecks[3], in both cases in the lower part and principally at the base of that formation, thus providing further evidence of the widespread occurrence of anhydrite and/or gypsum at the horizon of the Broken Beds.

While not questioning the presence of structures due to differential movements of tectonic origin in the Broken Beds, it seems desirable to add that if hydration of the anhydrite in a series of interbedded limestone-anhydrite beds occurred under moderate load, the 60 per cent increase in volume involved in the change from anhydrite to gypsum, might, if under pressure, the direction of which corresponded with that which produced the folding, lead to the formation of minor folds and even overfolds restricted to the belt of interbedded strata and having a direction corresponding to the regional strike.

Whatever the merits of the latter possibility it is suggested on the basis of the above facts that anhydrite was formerly present at the horizon of the Broken Beds and that its hydration and the subsequent solution of the gypsum were contributary factors in the formation of the Broken Beds.

S. E. Hollingworth.

Geological Survey and Museum.
8th April, 1938.

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[1] "The Jurassic Rocks of Britain," vol. v; "The Middle and Upper Oolitic Rocks of England," *Mem. Geol. Surv.*, 1895, p. 248.

[2] Bristow, H. W., Vertical Sections, Geol. Surv., Sheet 22.

[3] Lees, G. M., and Cox, P. T., "The Geological Basis of the Present Search for Oil in Great Britain by the D'Arcy Exploration Company, Limited," *Quart. Journ. Geol. Soc.*, xciii, 1937, 177, 180.

Sir,—I am much indebted to Dr. Hollingworth for sending me his interesting and constructive remarks and for giving me the opportunity to comment upon them.

(1) The Permian breccias described by Hickling and Holmes do not afford a satisfactory analogy because they lack the dip-and-strike structures of the Dorset breccia, as was pointed out in my paper (op. cit., p. 17). The argument that carries most weight to my mind, however, is that numbered (6) in my paper (p. 19), namely that the 14½ miles of outcrop in which the Broken Beds are developed coincide with the middle limb of the Purbeck Fold; that the 10 miles of outcrop from Ringstead to Portisham where no Broken Beds are recorded lie in the foreland of the fold and were already separated from the middle limb by the pre-Gault erosion. It should be noted that the gap of 2¾ miles between these two regions, where the change takes place, coincides with the passing of the outcrop from the middle limb on to the foreland; and since the gap represents only about 9 per cent of the whole mainland outcrop in length, this coincidence is unlikely to be due to chance. Moreover, the Broken Beds reach their maximum development about Lulworth, where the fold is "tightest" owing to thinness of strata, although this region is nearest to the unbroken foreland. At Lulworth, too, higher beds are involved than elsewhere, the whole Cypris Freestones being violently displaced and jumbled at the Fossil Forest.

(2) If the cause of brecciation had been salts interlaminated with the thin-bedded limestone, a more uniform and small-scale disintegration might have been expected. On the contrary, huge blocks from 1 to 2 feet thick are characteristic of the Lulworth Broken Beds. They are tilted but unshattered and do not show internally small-scale disturbance of the bedding such as described by Lamplugh and Kitchin in Weald boring cores.

(3) That previous expansion or removal of salts may have produced a plane of weakness which was responsible for localizing the differential movements at this horizon is highly probable. After reading Dr. Hollingworth's note I re-examined the Ringstead section (the first and best section on the foreland after passing westward off the middle limb), and I think enough can be seen there to support his suggestion. On a horizon corresponding with the lower part of the Lulworth Broken Beds there is for a foot or two vertically a band of puckering and obscure disturbance, and locally even small-scale brecciation, which I had been inclined to attribute to compaction against the underlying irregular tufas, enhanced by a certain amount of differential movement during the intra-Cretaceous folding, in which the beds were tilted to 35 degrees. This may well indicate a horizon at which anhydrite has changed to gypsum and then been removed, and such a plane of weakness might have determined the level at which the subsequent differential

sliding took place in the Lulworth district and Purbeck. I would therefore add this possible cause of the localization of movement to the twó suggested in my paper (p. 21). Probably the three causes combined to produce the present remarkable effects when the Tertiary folding set the rocks in motion.

W. J. Arkell.

THE AGE OF THE ELSWORTH ROCK.

Sir,—Dr. Spath's change of ground is bewildering. In his first letter he claimed to have anticipated my conclusions. In his second letter, unable, when challenged, to produce the references or justify his charges, he applies himself to destroying the conclusions. In the well-known manner of S. S. Buckman he splits up the stratigraphical units and refers mysteriously to missing foreign faunas. By this means doubt can be cast on any correlation.

Study in recent years of Corallian ammonites in museums from the west of France to Berlin and from Scotland to the Rhone Valley, combined with a little collecting, has convinced me that our Corallian Beds are very well representative (except in the upper parts not germane to this discussion), and that broad zones such as I use are all that there is scientific basis for using. I have not heard from those in charge that Dr. Spath has examined any of these collections. To assert an opinion, still more assume superior knowledge, without doing so is unjustifiable. The literature and foreign material in this country are far too meagre. Dr. Spath, moreover, has much field work to do before he can show the inapplicability of these zones in England.

With regard to the new subject raised by Dr. Spath, concerning the types of *Am. serratus* Sow. and *Am. cordatus* Sow., the course I have taken is that which involves least alteration of the usage of the last century or more. In the case of *Am. serratus* I have upheld the conclusion of the reviser, Salfeld, against a subsequent reversal by Dr. Spath (although from the latter's sentence, containing the words "chaos" and "gratuitous alteration", the reader derives just the opposite meaning). *Am. cordatus* is more complicated and there has yet been no reviser. As the matter will be discussed with full documentation in my monograph I need not encroach on your space by anticipating the account except to say that what I advocate is adherence to the interpretation of *Am. cordatus* made by the leading Jurassic palaeontologists and stratigraphers of several generations, so that it can continue to be used as index fossil for the Cordatus Zone, one of the first to be named (in 1852) and constantly recurring in world literature ever since.

W. J. Arkell.

University Museum,
Oxford.
9th May, 1938.

Sir,—I am sorry if Dr. Arkell is bewildered, and I will do my best to clarify the position. All the points raised can only be resolved by dispassionate reading of my Kachh Memoir (*Palaeontologia Indica*, N.S., vol. ix, No. 2, pt. 6, 1933) and my previous letters, which contain the justification of the charges which Dr. Arkell says I am unable to produce. Some of his latest statements only amount to *argumentum ad hominem*, familiar in discussions of this sort. As a rule, this method needs no reply, but comment on some of the points raised seems justifiable in the present case.

What Dr. Arkell interprets as a change of ground on my part is of course only the development of a complicated argument. He is quite right in referring to S. S. Buckman's method of splitting up stratigraphical units as well known ; the work of this genius may be more fully appreciated by future generations, and I am quite content to be on his side in this respect. But I have not referred mysteriously to anything ; rather would it seem that the things I referred to are mysterious to Dr. Arkell.

As regards the second paragraph of Dr. Arkell's letter, I need only say that the collections of Corallian ammonites in the British Museum (Natural History), on which I have had the privilege of working for twenty-five years, include foreign as well as British specimens, and nobody who has seen them all could describe the foreign material as meagre.

My mention of the two ammonite-species referred to in Dr. Arkell's third paragraph does not constitute the introduction of a new subject. It merely draws attention to the means by which he has been able to produce some of the arguments which I regard as specious. The fact that he follows the lead of other palaeontologists is not relevant : two (or more) wrongs never yet made a right.

Dr. Arkell can only maintain his position in regard to *Am. cordatus* Sowerby (the status of which has of course been fixed by the works of Healey, Crick, and Buckman) by electing to disregard the Rules of Nomenclature. I submit that this is an attitude to be deplored, especially when adopted by one who has undertaken monographic work.

L. F. Spath.

British Museum (Natural History).
20th May, 1938.

[This correspondence is now closed.—Ed.]

ERUPTION OF NYAMLAGIRA.

Sir,—I have received a letter from Dr. J. Verhoogen, of the Laboratory of Applied Geology in the University of Brussels, in which he gives a vivid description of the eruption now proceeding at Nyamlagira, one of the largest volcanoes of the Virunga (or Bufumbiro) group in the Kivu region of the Belgian Congo. It may be of interest to transcribe some of Dr. Verhoogen's observations. Dr. Verhoogen says :—". . . as one of these volcanoes, Nyamlagira, has been kind enough to erupt, all my time is spent in watching this eruption of a rather peculiar type. The eruption has lasted now (April 17) about eighty days, and the daily output of lava amounts to no less than one million cubic meters. . . . The mechanics of the eruption seem to be quite complicated, as the lava does not merely flow out from a fissure. Besides the actual source of the lava stream, there is a lava pool in which the lava enters on one side and goes out on the opposite side, and a few small cones belching gigantic yellow flames and occasionally also incandescent material. I have not yet been able to figure out whether the lava actually flows out from the pool into the lava stream, or whether the circulation in the pool is caused mainly by convection. I have not figured out either what is the use of the cones, as they are born and die out without any apparent change in the lava pool, or in the temperature or output of the lava stream. The sight at night is magnificent, and the whole thing is stimulating material for geological thought, as nothing seems to work according to theory. . . . As this volcano has been permanently active for nine years (Hawaiian activity) it is hoped that when this eruption ends the lava will return to the main crater."

In another place Dr. Verhoogen says that the new crater, the lava pool, the cones, and the source of the lava, etc., are located 3,000 feet below the actual caldera, and wants to know whether there are any known examples of volcanoes of Hawaiian type in which the whole activity which is usually displayed in the crater may be displaced to the foot of the volcano, either permanently or temporarily. Possibly Nyamlagira has been built up to the maximum height and size permitted by the available volcanic energy, and the heavy basaltic lava is now breaking out in fissure eruptions on the flanks and at the foot of the structure. According to the observations of H. T. Stearns and W. O. Clark (Geology and Water Resources of the Kau District, Hawaii, *Water-Supply Paper* 616, *U. S. Geol. Surv.*, 1930) the typical Hawaiian shield volcanoes appear to be approaching this stage.

G. W. Tyrrell.

The University, Glasgow.
3rd June, 1938.

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ORIGINAL ARTICLES.

Anemetocrinus N.G. A Five-armed Poteriocrinid from the Lower Carboniferous Limestones of Scotland.

By James Wright.

(PLATES XIII AND XIV.)

I. INTRODUCTION.

IN the Scottish Lower Carboniferous limestones there are known to occur at least seven species of Dicyclic Inadunate crinoids belonging to the family *Poteriocrinidae*, one of the main characters of which is the possession of five simple unbranched arms. One species is also known from the Carboniferous of the Isle of Man. Two of the Scottish species have been assigned to the genus *Ulocrinus*, viz. *U. globularis* de Koninck and *U. doliolus* Wright. The former species is now referred to *U. bockschii* (Geinitz), which has priority, and the Scottish specimens as they commonly occur appear to be indistinguishable from it. The cup in these two species is specially characteristic, the shape being for the most part globular and the anal area, while sometimes of normal character, is more commonly occupied by a large RA with anal X and rt surmounting it and comparatively small. The arms are rather long, uniserial, and formed of narrow cuneiform brachials (Plate XIV, Figs. 1–6). (Bather, 1916–17 ; Wright, 1927, 1936.)

The other six species are more difficult to place. Here the cup is conical, the anal area is of normal character, i.e. RA and anal X are fairly large, the latter joining up with the post. B which along with rt is well within the limits of the cup. The brachials are cuneiform, interlocking, wedge-shaped or tongued together, and the arms thus range from uniserial to a structure which to all intents and purposes is biserial. For want of a better resting-place four of these species have been previously referred to *Scytalocrinus* because of a general resemblance in habitus and because in that genus certain species have less than the normal ten arms (Wright, 1934, 1938). Recently the discovery of a fine new species in the Seafield Tower Limestone in Fife, remarkable for the biserial nature of the arms throughout, has opened up the question afresh and has led me to re-examine all the specimens of five-armed *Poteriocrinids* in my collection. As a result of this examination a new genus is now proposed for the reception of four of the species of which two are here described for the first time.

Crinoids with five simple arms are rare in Carboniferous rocks, although one cannot overlook the occurrence in the Lower Carboniferous of Russia of *Cromyocrinus simplex* Trautschold recorded as far back as 1867 and *Poteriocrinus originarius* Trautschold which was recorded at the same time and probably comes into the same category. The former species has only five arms, but the drawings of the latter species given by Trautschold show that the right post. ray branches on the second primibrach giving a total of six arms. The figures on the accompanying plates are, however, not quite convincing as to the accuracy of this and it may be that this species has also only five arms (Trautschold, 1867, 1874). In *C. simplex* the brachials are cunieform, in *P. originarius* the arms are very long and the brachials range from cuneiform near the cup to very short quadrangular plates distally. Another species of *Cromyocrinus* (*C. gracilis* Wetherby) has been recorded from the Kaskaskia (Chester) group in Kentucky, U.S.A. In this species the arms number five and are composed for the most part of short quadrangular brachials (Wetherby, 1880). This species has also been referred to *Eupachycrinus* (Wachsmuth and Springer, 1886). Another American species of very similar character, *Zeacrinus pulaskiensis*, was described by Miller and Gurley in 1895 from the same group. In 1896 these authors also described *Poteriocrinus bozemanensis*, a small five-armed form with conical cup from the Madison Limestone of Montana.

Lophocrinus minutus (Roemer), dating from 1854, is also a five-armed form which occurs in the Carboniferous of Germany, but since the cup here, although conical, has an anal area usually filled with a large anal X to the exclusion of other plates it is placed in another family (*Lophocrinidae* Bather). It therefore need not be further considered here. (Jaekel, 1895; Schmidt, 1930.)

In 1933, L. R. Laudon proposed the genus *Gilmocrinus* for the reception of a *Poteriocrinid* occurring near Gilmore City, U.S.A., which has usually five simple arms but in some specimens has up to six and seven. The cup is conical with normal anal area, the arms being uniserial and formed of rather narrow cunieform brachials. When branching is observed it occurs on the first primibrach in one or two arms, but seems to be sporadic and is not confined to any special ray or rays. The total number of arms does not appear to exceed seven and five is the more usual number. In studying this genus it at first seemed possible that the six Scottish species together with the single Isle of Man species, all showing the five-armed character, could quite well be referred to it, but four of the Scottish species differ so much from the American genus in the general character of the arms as to form a distinctive and remarkable group. They therefore appear to me to justify the creation of the new genus now proposed for them. The remaining two species conform more to the characters of *Gilmocrinus* and are here placed under it. Unfortunately, the ventral sac is not preserved in any of our specimens.

II. DESCRIPTION OF SPECIES.

POTERIOCRINIDAE Roemer (emend. Wachs. and Spring.).

POTERIOCRININAE Springer.

ANEMETOCRINUS[1] Gen. Nov.

A Poteriocrinid with five simple unbranched arms, wholly or partly biserial; brachials wedge-shaped to interlocking, wedge-shaped to quadrangular, or wedge-shaped throughout; cup conical, low, or elongated, anal area normal with RA, anal X and rt within limits of cup.

(1) Genotype *Anemetocrinus biserialis* sp. nov.

Plate XIII, Fig. 9; Plate XIV, Fig. 7.

A robust species; cup conical, low, about three times wider than high, anal area normal; arms five, long, rather heavy in appearance, brachials tongued or dovetailed together and markedly biserial throughout; pinnules springing from each brachial; plates smooth.

Holotype.—J. Wright Coll. No. 2317.

Locality.—No. 2 Bed, Seafield Tower Limestone, shore, west of Kirkcaldy, Fife.

Horizon.—Lower Limestone Group.

Dimensions of holotype.—Full length of crown, 4⅛ inches (104·7 mm.); diameter of cup, estimated, 14·7 mm.; height of cup, estimated, 5 mm.; width of arms near cup, 6 mm.; width of arms at distal end, 3 mm.

Remarks.—The holotype is a unique and rather striking specimen, the only nearly complete crown of the species so far found. When taken from the rock, the cup and proximal part of the arms were invisible and embedded in a hard shaly matrix, and it was only with difficulty that this part of the crown could be exposed. The striking feature about the specimen is of course the biserial nature of the arms throughout. Unfortunately, the exact junction with the radials of the cup is nowhere seen, but the proximal brachials, of which one or perhaps two are displaced or missing, although probably larger, do not appear to have differed very much in size from those now forming the proximal ends of the arms now seen in the photographs. This is inferred from the evidence of some scattered plates near the cup and from the smaller species *A. ardrossenis* sp. nov. and others described below, where it is evident that it is the first brachial only which is somewhat larger than the brachials immediately succeeding it. The biserial character is specially well shown in the two rays which are lying extended to the left and right of the cup (Pl. XIII, Fig. 9; Pl. XIV, Fig. 7, Text-fig. 1). Both have the dorsal surface upward and show the somewhat rounded nature of the arms as well as the manner in which the brachials are wedged or dovetailed into one another. Proximally, the ray on the left remains unaltered for rather more than a third of its total length, at which point a break occurs and the remainder of the arm is twisted to the left, exposing to view a few of the lower plates of the pinnules and the edges of the pinnular sockets on the brachials. We thus get a side view of this part of the arm. The ray on the right is less disturbed but is slightly twisted to the right in the distal region. Partly underneath this ray, on the extreme right of crown, is another one with ventral surface upward and exposing, especially towards the distal end, the pinnular sockets of the right side of this arm very clearly. Underneath the ray on the left of crown is another ray also with ventral surface upward but here the details are obscured. The fifth ray has almost disappeared, although remains of it can be seen at the bottom right of photograph. The orientation of the rays is not possible to determine with certainty, the cup being displaced and squeezed down between the arms. The anal side of the cup is also disturbed and more or less buried in the matrix, the anterior radial being at the top of the cup as it lies just between the two arms. That the anal area is of normal character I have no doubt. This may be judged not only from the general shape of the cup itself but also from the lower end of the RA, which can be seen adjoining the right post. and post. basals, and from the occurrence of similar cups near at hand. One of the latter is shown on Pl. XIII, Fig. 8. The proximal columnal is still adherent to the cup of the holotype but is absent in this cup, which is noteworthy in that the IBB link up with the RR. This feature is not apparent in the cup of the holotype where the IBB are clearly separated from the RR, but is a type of variation which also occurs in the cups of the multi-armed *Hydreionocrinus* found on the same horizon. Cups of the latter genus, however, are easily distinguished from those of *A. biserialis*. In *Hydreionocrinus* the plates are always ornamented with granules or pustules. The plates in *A. biserialis* are quite smooth and devoid of any ornamentation. About 1½ inches of the proximal part of the column is preserved but somewhat displaced near the cup. It is of a nodular type and consists of rounded alternating thick and thinner columnals.

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[1] *ανέμητος* = undivided, in allusion to the unbranched arms.

(2) *Anemetocrinus ardrossensis* sp. nov.

Plate XIII, Figs. 4, 6, and 7.

A small species; cup conical, elongated; arms rather heavy, tending to biserial; brachials wedge-shaped in proximal region, the pointed ends meeting half-way across the arms, becoming more interlocking distally, the pointed ends occasionally almost reaching the opposite side of arms.

Holotype.—J. Wright Coll. No. 2342.

Locality.—Ardross Limestone, shales above, Ardross, Fife.

Horizon.—Calciferous Sandstone Series.

Dimensions of holotype.—Length of crown preserved, 36·5 mm.; width of cup across RR, 6·3 mm.; height of cup, 4 mm.

Another cup.—Width, 8·3 mm.; height, 6·5 mm.

Remarks.—This is a comparatively small species with very characteristic arms. The cup is more elongate than in *A. biserialis*. The holotype is not complete although it shows part of four arms, one of which is still attached to the cup and is slightly twisted to the right. This arm shows that in the proximal region, especially up to the eighth or ninth brachial, the pointed ends of the wedge-shaped brachials only meet about half-way across the arm which is thus biserial in character, and in shape gently rounded (Text-fig. 2). As shown by the ray in the centre, at about the tenth brachial the arm becomes somewhat narrower and more elevated and the pointed ends of the brachials tend to continue further over towards the other side. Although none of these brachials are seen to cross exactly to the other side, this tendency seems to increase, and since the arms are incomplete may indicate that the brachials become more cuneiform towards the arm tips. The ray on the right of specimen is the most complete and shows the junction of the first brachial with the cup (Pl. XIII, Fig. 4, Text-fig. 2). I am figuring two cups of the species from the same locality and both show the first brachial resting on the radials (Pl. XIII, Figs. 6 and 7). These cups are larger than the cup of holotype and indicate that the species attained somewhat greater dimensions than the holotype. Altogether I have ten of these cups from Ardross, varying in size but none larger than those figured, and all show the first brachials in position. I have also three somewhat disturbed crowns from the shales above the "White Limestone" of St. Monance Burn, a much higher horizon than the Ardross Limestone and more nearly on the position of the Seafield Tower Limestone of the Kirkcaldy area. These specimens are too badly preserved for determination, but the cup appears to be less elongated than in the Ardross forms. The arms are also less biserial in character, the wedge-shaped brachials being confined to the first four or five plates with the first brachial itself a longer plate than in *A. ardrossensis*. Probably these specimens belong to a distinct species.

(3) *Anemetocrinus pentonensis* (Wright).

Plate XIII, Fig. 1.

1934. *Scytalocrinus pentonensis* J. Wright, Geol. Mag., LXXI, 250, Pl. XIV, Fig. 3, Text-fig. 20.

A rather clumsy species; cup conical; arms five, brachials heavy, cuneiform and interlocking distally, ridged and almost triangular in section, rounded and wedge-shaped with tendency to biserial near cup, pinnules on alternate brachials.

Holotype.—J. Wright Coll. No. 2247.

Locality.—Penton Linns, Liddesdale.

Horizon.—Lower Limestone Group.

Dimensions of holotype.—Length of crown, 2⅞ inches (72·9 mm.); diameter of cup, estimated, 12 mm.; height of cup, estimated, 5 mm.

Remarks.—This species is known from two specimens both found at the same locality, but the holotype is much better preserved and shows the cup and arms in finer detail. The first four brachials in each arm are stout wedge-shaped plates, rather rounded, and excepting the first brachial which rests on the radial do not cross the arm from side to side, the pointed ends of the second, third, and fourth brachials meeting rather over the centre line of the arm. While perhaps not strictly biserial this structure certainly tends in that direction and shows the relationship of the species to *A. biserialis* and *A. ardrossensis.* The fifth brachial is a shorter plate and is wedged in between the fourth and sixth brachials crossing rather further over the arm than the proximal brachials. Succeeding brachials tend to become more interlocking and cuneiform distally. The sixth brachial is somewhat cuneiform and is of the full width of the ray. Succeeding it is another interlocking short plate not quite reaching the other side but going further in this direction than the fifth brachial. Then follows another cuneiform plate crossing from side to side. For some distance distally this type of structure continues, but the shorter and interlocking brachials now reach from side to side until they gradually become more regularly cuneiform towards the distal ends of the arms (Pl. XIII, Fig. 1, Text-fig. 3). Altogether the arms in this species have a somewhat clumsy appearance. At the proximal end they may be described as rounded, but from where the interlocking and cuneiform brachials begin the shape is somewhat ridged and almost triangular in section. There is nothing noteworthy about the cup, which is of the usual conical shape but is somewhat squeezed in the holotype.

(4) *Anemetocrinus covensis* (Wright).

Plate XIII, Fig. 5.

1934. *Scytalocrinus covensis* J. Wright, Geol. Mag., LXXI, 250, Pl. XIV, Fig. 1, Text-fig. 21.

A rather elegant species; cup conical; arms five, rounded, brachials wedge-shaped near cup, quadrangular distally.

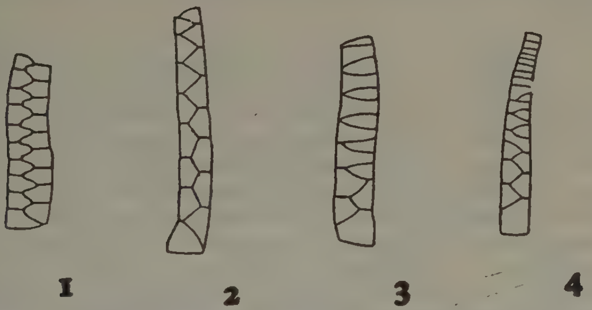
Holotype.—Scottish Geological Survey Coll. No. B 3700*e.*

Locality.—Cove Harbour, Cockburnspath, Berwickshire.

Horizon.—Calciferous Sandstone Series.

Dimensions of holotype.—Length of crown, 65 mm.; width of cup, estimated, 11 mm.; height of cup, estimated, 7·6 mm.

Remarks.—This species is a more elegant form than the three previously described, the arms being more rounded and tapering. Its chief feature perhaps is the somewhat rapid change that takes place in the arm structure from the rudely biserial nature of the brachials in the lower third of the arms to the upper two-thirds which are quadrangular (Text-fig. 4). The wedge-shaped brachials near the cup number nine or ten before they merge into the more regular quadrangular series. The cup is very similar to that of *A. pentonensis*. The first brachial in this species is relatively longer than in the three preceding species.



TEXT-FIGS. 1–4.—Types of arm structure in *Anemetocrinus.* Fig. 1, *A. biserialis*; Fig. 2, *A. ardrossensis*; Fig. 3, *A. pentonensis*; Fig. 4, *A. covensis.* Nat. size.

(5) *Gilmocrinus arbiglandensis* (Wright).

Plate XIII, Fig. 3.

1934. *Scytalocrinus arbiglandensis* J. Wright, GEOL. MAG., LXXI, 250, Pl. XIV, Fig. 6, Text-fig. 19.

Cup conical; arms five, somewhat flat, brachials moderately cuneiform, becoming quadrangular distally.

Holotype.—J. Wright Coll. No. 75.

Locality.—Arbigland shore, Solway Firth, Kirkcudbrightshire.

Horizon.—Calciferous Sandstone Series.

Dimens of holotype.—Width of cup, 12 mm.; height of cup, 7 mm.

Remarks.—There is no sign of biserial structure in the arms of this species, so that it seems to come well within the limits of *Gilmocrinus.* The brachials are for the most part cuneiform, but in the longer arm preserved in the holotype they become more quadrangular distally and probably continue so to the arm tips. The length of the arms is unknown, the holotype being incomplete and the only specimen known.

(6) *Gilmocrinus beggi* (Wright).

Plate XIII, Fig. 2.

1938. *Scytalocrinus beggi* J. Wright, GEOL. MAG., LXXV, Pl. XIII, Fig. 2.

A rather delicate species; cup elongated, higher than wide; brachials cuneiform, moderately long, rounded.

Holotype.—J. L. Begg Coll.
Locality.—Cass-ny-hawin, Isle of Man.
Horizon.—C 2.
Dimensions of holotype.—Width of cup, 8·5 mm.; height of cup, 9·5 mm.

Remarks.—This species also seems to come well within *Gilmocrinus*, the arms so far as preserved being composed of cuneiform brachials and apparently being rather long. The cup here is more elongated than in *Gilmocrinus arbiglandensis* or in the American species of this genus. The anal area is not definitely known but is assumed to be normal.

III. SUMMARY OF FIVE-ARMED *POTERIOCRINIDAE.*

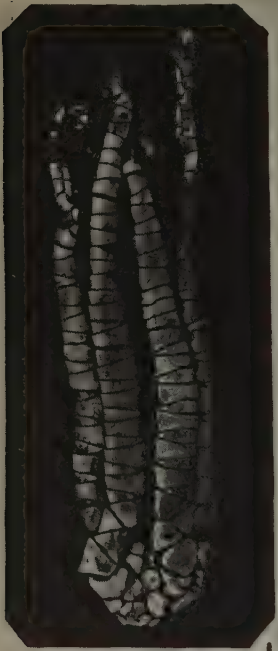
In this paper six species are described or redescribed, all of which are characterized by the possession of five simple arms. Four of these have arms which are wholly or partly of a biserial nature and are now referred to the new genus *Anemetocrinus*. The other two which have uniserial arms are referred to *Gilmocrinus* Laudon. The biserial nature of the arms in *Anemetocrinus* reaches its maximum development in *A. biserialis*, and while not perhaps reaching the same degree as that shown in the multi-branched genus *Hydreionocrinus*, which occurs on the same platform, it has advanced considerably in that direction. Curiously enough the modifications of the arm structure in the four species of *Anemetocrinus*, i.e. from biserial to uniserial, are the reverse of what one might naturally expect in the development of biserial arms. This aspect of the matter cannot be discussed here. Meanwhile, so far as known, one might arrange the five-armed *Poteriocrinidae* as follows :—

Five arms, uniserial, Br cuneiform or quadrangular ; cup bowl-shaped, anal area normal : *Cromyocrinus simplex* Trautschold, *Cromyocrinus gracilis* Wetherby, *Zeacrinus pulaskiensis* Miller and Gurley.

Five arms, uniserial, Br cuneiform ; cup globular, anal area advanced, occasionally normal : *Ulocrinus bockschii* (Geinitz), *Ulocrinus doliolus* Wright.

Five to seven arms, uniserial, Br cuneiform, or cuneiform to quadrangular ; cup conical, elongate, anal area normal : *Gilmocrinus iowensis*, Laudon, *Gilmocrinus o'neali* Laudon and Beane, *Gilmocrinus arbiglandensis* (Wright), *Gilmocrinus beggi* (Wright), *Gilmocrinus* (*Poteriocrinus*) *originarius* (Trautschold), *Gilmocrinus bozemanensis* Miller and Gurley.

Five arms, wholly or partly biserial, Br wedge-shaped, wedge-shaped to interlocking or to quadrangular ; cup conical, low, or elongate, anal area normal : *Anemetocrinus biserialis* sp. nov., *Anemetocrinus ardrossensis* sp. nov., *Anemetocrinus pentonensis* (Wright), *Anemetocrinus covensis* (Wright).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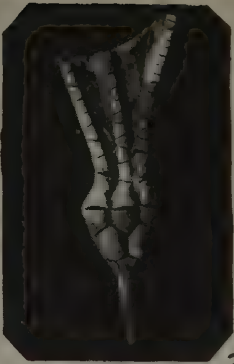
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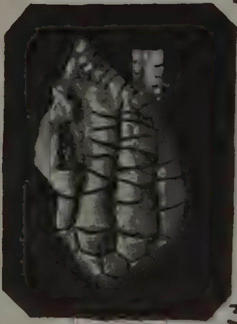
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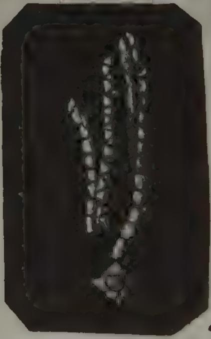
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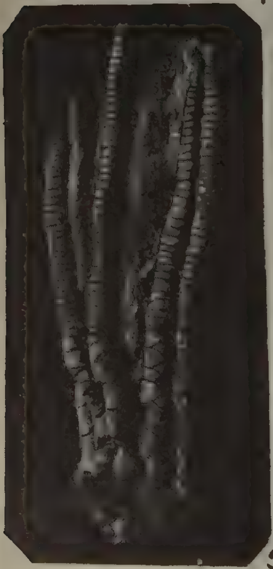
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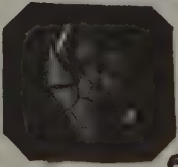
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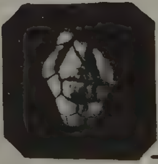
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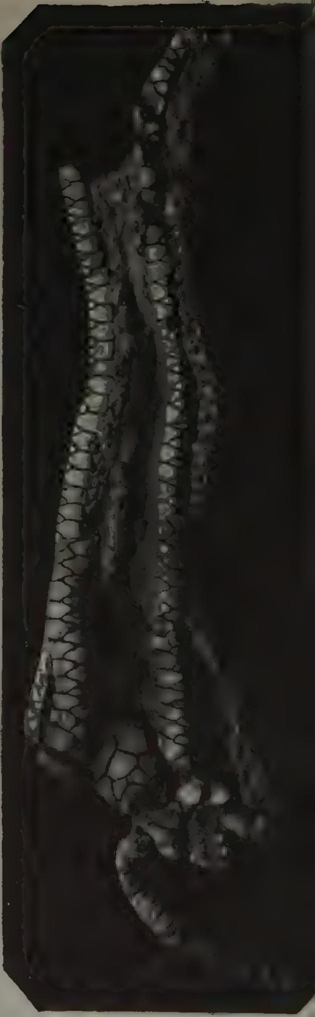

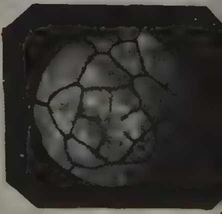

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ANEMETOCRINUS AND *GILMOCRINUS*.

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V. EXPLANATION OF PLATES.

Plate XIII.

Figs.

1.—*Anemetocrinus pentonensis* (Wright) from Penton Linns, Liddesdale, posterior view of the holotype, J. Wright Coll.

2.—*Gilmocrinus beggi* (Wright) from Cass-ny-hawin, anterior view of the holotype, J. L. Begg Coll.

3.—*Gilmocrinus arbiglandensis* (Wright) from Arbigland, Solway Firth, anterior view of the holotype, J. Wright Coll.

4.—*Anemetocrinus ardrossensis* sp. nov. from Ardross, Fife, anterior view of the holotype, J. Wright Coll.

5.—*Anemetocrinus covensis* (Wright) from Cove Harbour, Berwickshire, the holotype, Scottish Geol. Survey Coll.

6 and 7.—Posterior and anterior views of cups of *Anemetocrinus ardrossensis* sp. nov. from Ardross; Fig. 6 shows the first Br in position on left post. R and in Fig. 7 the first Br is on each of the three RR. J. Wright Coll.

8.—Cup of *Anemetocrinus biserialis* sp. nov. from Seafield, near Kirkcaldy, J. Wright Coll.

9.—*Anemetocrinus biserialis* sp. nov. from Seafield near Kirkcaldy, the holotype, J. Wright Coll.

All Figs. nat. size except Figs. 6 and 8 which are × 1½.

PLATE XIV.

FIGS.
1, 3, 4, and 6.—Cups of *Ulocrinus bockschii* (Geinitz) (*U. globularis* de Kon.) showing variation in anal area, from No. 1 Bed Invertiel, J. Wright Coll.
2.—*Ulocrinus doliolus* Wright from Encrinite Bed, St. Andrews, the holotype, J. Wright Coll.
5.—*Ulocrinus bockschii* (Geinitz), anterior view of an incomplete crown from Penton Linns, Liddesdale, with part of three arms in position; the cup is somewhat flattened. J. Wright Coll.
7.—*Anemetocrinus biserialis* sp. nov., the holotype, J. Wright Coll.
All Figs. nat. size except Fig. 7 which is × 1½.

On Floral Subdivisions in the Yorkian Stage in South Wales.

By R. CROOKALL.

INTRODUCTION.

THE papers on the floras of the Carboniferous rocks, published in recent years by Dr. Emily Dix [7, 8], collectively form an important contribution to our knowledge of British Carboniferous palaeobotany. In these publications a floral classification was proposed for the Carboniferous strata of the Swansea district and an endeavour was made to apply it to other British and to foreign coalfields. The present writer, however, considers that some modification of the suggested scheme is necessary in regard to the strata included in the Yorkian Stage. Until this is done the classification will not be applicable to areas outside South Wales.

The dividing lines taken by Kidston and the present writer in the Upper Carboniferous of South Wales are as follows: between the Lanarkian and the Yorkian, the Cnapiog Seam [4]; between the Yorkian and the Staffordian, the No. 3 Rhondda [10] (= Lower Pinchin [4]) Seam; between the Staffordian and the Radstockian, the Hughes Seam [5]. These compare with the three main dividing lines of the proposed classification of Dr. Dix[1] as follows: Zones C and D were delimited just below the Lower Vein, Zones F and G at the Lower Pinchin, and Zones G and H at just below the Glyn Gwilym Seam (the coal next below the Hughes). According to that author, the divisions of the rocks included in the Yorkian stage, together with their "index species", are to be tabulated as follows:—

Zone of *Neuropteris tenuifolia*
Neuropteris callosa
Asolanus camptotaenia
Lepidodendron simile
} Flora F.

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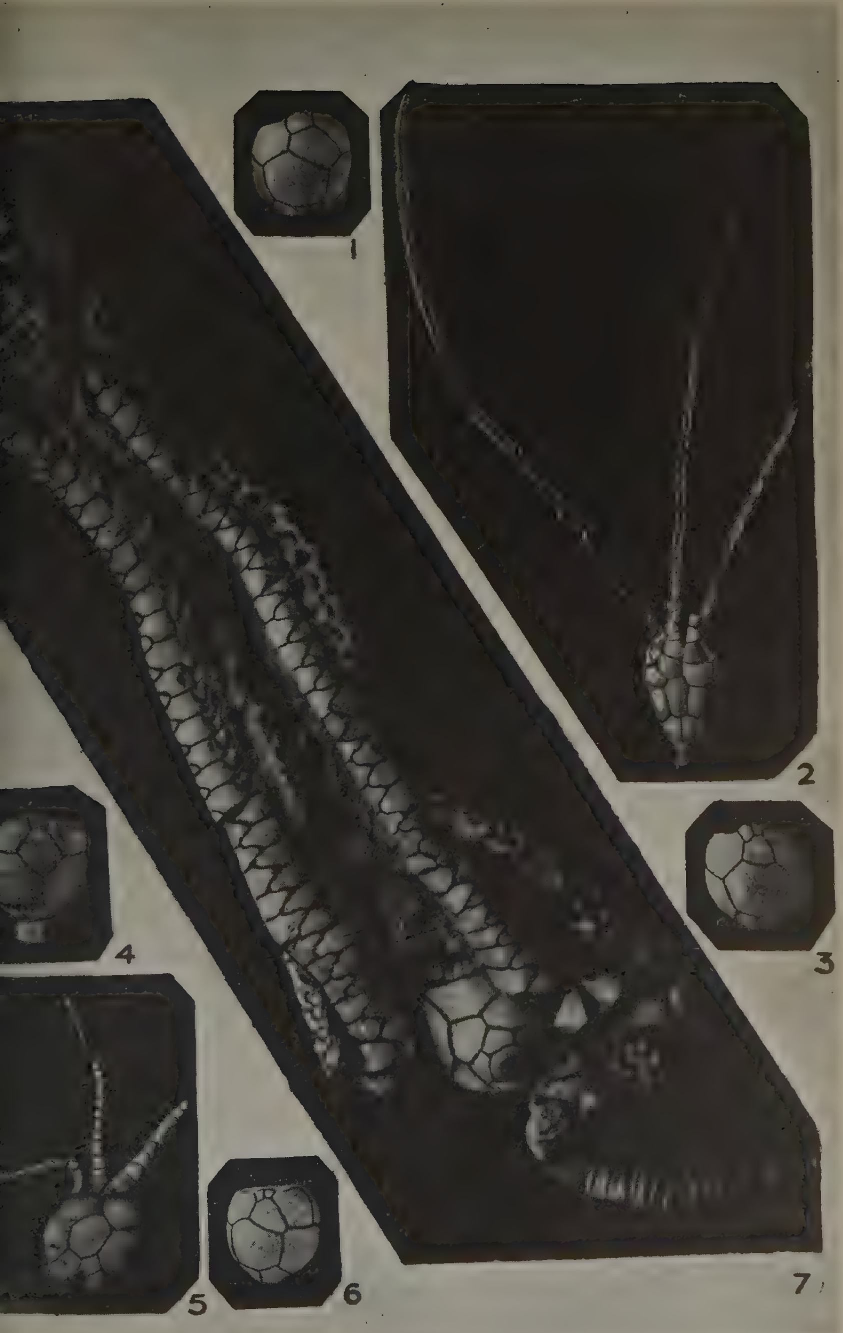
[1] The correct terms, "The Zone of Flora D," "E" (etc.), are abbreviated in the present paper to "Zone D," "E" (etc.).



J. Wright Photo.

ANEMETOCRINUS AND ULOCRINUS.

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Zone of	*Lonchopteris rugosa* *Neuropteris gigantea* *Sphenophyllum myriophyllum* *Sphenophyllum majus* *Annularia microphylla* *Sphenopteris spp.*	Flora E.
Zone of	*Alethopteris lonchitica* *Neuropteris heterophylla*	Flora D.

In addition to the assemblages of " index species " quoted above, Dr. Dix cited additional species in the text of her paper. In order to distinguish these, the former are here designated " index " and the latter " additional "[1] species.

Synopsis of Floras and Zones (D, E, and F).

Dr. Dix prefaced her complete floral lists of each Zone with a list of localities and horizons and, in the tables, indicated the frequency of occurrence of each species at a given horizon using the letters D = dominant ; S = subsidiary ; R = rare.

In the present résumé the writer has taken each zone as a unit and has indicated the total number of horizons on which a particular species is dominant, subsidiary, or rare, using as a basis for the statements of frequency and horizon only those published by Dr. Dix, e.g. D 1, S 2 indicates that a species was described as dominant on one horizon and subsidiary on two.

Flora D was described [8] as " more or less intermediate in character " between Floras C and E and it is therefore not surprising that Dr. Dix [7] found it " impossible to draw a definite line " between Zones D and E. Although a similar observation was not made in regard to the separation of Zones E and F, an examination of the records shows that that line also is indefinite : the highest horizon examined in Zone E yielded no examples of the " index " species regarded as characteristic of that division[2] ; on the other hand, the lowest horizon examined in Zone F yielded six " zonal " species, of which three (*Neurop. gigantea*, *Sphen. myriophyllum*, and *A. microphylla*) were described as typical of Zone E and three (*Neurop. pseudogigantea*, *N. tenuifolia*, and *Lepid. simile*) as characteristic of Zone F.

In comparing Zones D and E it should be observed (i) that *Sphenopteris obtusiloba* was described in 1933 by Dr. Dix [7] (p. 800) both as a " dominant " species of Zone D and (p. 803) as a " characteristic Sphenopterid " in Zone E ; and (ii) that *Alethopteris decurrens* was described (p. 800) both as " dominant " in Zone D and (p. 803) as a " principal species of *Alethopteris* " in Zone E.

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[1] In the opinion of the present writer the word " subsidiary " would be more applicable. This word, however, is used by Dr. Dix to indicate the relative frequency of a species on an horizon and such connotation is here continued.

[2] The Soap Vein yielded two forms, *Alethop. decurrens* and *Lepid. rimosum*, both rare. The former is an additional species for Zones D and E and the latter an additional species of " Flora G ".

TABLE I.

Kidston-Crookall divisions :—	Lanark-ian.	Yorkian.			Stafford-ian.
Zone of Flora :—	C[1]	D	E	F	G[1]
Total number of horizons :—	3	9	8	5	6
"FLORA F."					
(*a*) "Index" species :					
Neurop. tenuifolia (Sch.)	—	—	S2, R2	D1, S2	D3, S1
,, *callosa* Lesqx.	—	—	R2	S2	S2
Asol. camptotaenia Wood	—	—	—	D1, S1	D1, S2
Lepid. simile Kidst.	—	—	S1	D3	—
(*b*) "Additional" species :					
Neurop. pseudogigantea P.	—	—	S2	D2	S1
,, *gigantea* Bgt.	R1	D1, S1	D2, S4	S5	S4
,, *obliqua* Bgt.	—	D3, S1	D2	S3	S1, R1
Ann. microphylla Sauv.	—	R1	D1, S1	S2	R1
"FLORA E."					
(*a*) "Index" species :					
Lonchop. rugosa Bgt.	—	—	R1	—	—
Neurop. gigantea Stb.	R1	D1, S1	D2, S4	S5	S4
Sphen. myriophllum Crép.	—	—	S1, R2	R1	—
,, *majus* Bronn.	—	—	D1, S1	—	S1, R2
Ann. microphylla Sauv.	—	R1	D1, S1	S2	R1
Sphen. obtusiloba Bgt.	—	D1	S1, R1	—	S2
,, *dilatata* L. and H.	—	—	S1, R1	—	—
,, *trifoliolata* (Art.)	—	—	S1, R1	—	S1, R1
,, *laurenti* Andr.	—	—	D1, S1	—	R1
Diplot. furcatum (Bgt.)	—	R1	D1, S2, R1	—	—
(*b*) "Additional" species :					
Dactyl. plumosa (Art.)	R1	R1	D1, S2	—	D1, S1
Alethop. davreuxi (Bgt.)	—	—	D1	—	—
Mariop. muricata (Sch.)	—	S2, R1	D1, S3	R2	R2
Alethop. decurrens (Art.)	D1	D1	D1, S4, R1	R1	—
"FLORA D."					
(*a*) "Index" species :					
Alethop. lonchitica (Sch.)	D2	D1, S1, R2	D1, S1	—	S1
Neurop. heterophylla Bgt.	—	D1, S2, R1	D1, S4, R1	R2	R1
(*b*) "Additional" species :					
Neurop. obliqua Bgt.	—	D3, S1	D2	S3	S1, R1
,, *grangeri* Bgt.	—	D1, S1	R1	—	—
Sphen. obtusiloba Bgt.	—	D1	S1, R1	—	—
Alethop. decurrens (Art.)	D1	D1	D1, S4, R1	R1	—
Mariop. muricata (Sch.)	—	S2, R1	D1, S3	R2	R2

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[1] Species other than those listed above occur in Zones C and G ; these are he omitted since we are concerned primarily with Zones D, E, and F.

In Table II (below) are shown other plants from Dr. Dix's complete lists which, though neither " index " nor " additional " species, the present writer finds could have been included among the latter.

TABLE II.

idston-Crookall Divisions :—	Lanark-ian.	Yorkian.			Stafford-ian.
one of Flora :—	C	D	E	F	G
umber of horizons :—	3	9	8	5	6
FLORAS E AND F."					
epid. ophiurus Bgt.[1] . .	—	R2	D1, S2, R2	D1, S2	S2
FLORA E."					
phen. cuneifolium (Stb.) .	—	S2, R1	D1, S3	S2, R1	S3
igill. rugosa Bgt. . .	—	—	D1, S1	—	—
phen. saureuri Crép. . .	—	—	S2	—	—
„ *trigonophylla* Beh. .	—	—	S1	—	—
FLORAS C AND D."					
epid. obovatum Stb. . .	S2	S2	R2	—	R2

Table I shows that the two " index " species of Zone D, namely *Alethopteris lonchitica* and *Neuropteris heterophylla*, are also common in Zone E; that the former is dominant on two out of three horizons in Zone C and that the latter is actually more widely distributed in Zone E than in Zone D. In these circumstances, Flora D, as tabulated, cannot correctly be described as representing plants which primarily characterize Zone D. Of the " additional " species in Flora D, *Neuropteris grangeri* is more frequent in Zone D than in Zone E; if, on the other hand, *Alethopteris decurrens* has any diagnostic value as between Zones D and E, it is more typical of the latter than of the former. The other " additional " species of " Flora D ", namely, *N. obliqua*, *S. obtusiloba*, and *M. muricata*, give little or no help in differentiating between Zones D and E, if the number of available horizons be taken into account. It is evident that (*a*) *A. lonchitica*, *N. heterophylla*, and, to a less extent, *N. gigantea*, characterize the strata included in both Zone D and Zone E, and (*b*) the criteria distinguishing these ill-defined divisions from each other are mainly of a negative nature, viz. (i) the apparent absence from Zone D of certain species, none of which, however, was recorded from more than three out of eight horizons in Zone E, i.e. of *Lonchopteris rugosa*, *Sphenophyllum myriophyllum*, *S. majus*, *Sphenopteris dilatata*, *S. trifoliolata*, *S. laurenti*, and *Alethopteris davreuxi*; (ii) the apparent absence from Zone D of certain forms

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[1] See p. 350.

(*Neuropteris tenuifolia*, *N. pseudogigantea*, and *N. callosa*) [1] belonging to Flora F but occasionally found in Zone E.

The positive criterion consists merely in the relative frequencies of the species common to both divisions; *Annularia microphylla*, *Neuropteris gigantea*, *Diplotmema furcatum*, *Alethopteris decurrens*, and *Dactylotheca plumosa* appear to be of commoner occurrence in the higher division, while *N. grangeri* is more frequent in the lower zone. Whether these criteria, negative and positive, will survive the test of further collecting in South Wales is, in the present writer's opinion, doubtful; that they could be used to differentiate equivalent strata in other coalfields appears unlikely. In this connection it should be said that the writer [6] has not found *Neurop. heterophylla* quite so typical of the lower horizons of South Wales as did Dr. Dix, nor does his experience in other coalfields lead him to conclude that such is the case generally. In point of fact, difficulty has already arisen in regard to the vertical range of this species: in a recent paper on the Coal Measures of North Wales, Dr. A. Wood [12] observed, "The flood of undoubted *Neuropteris heterophylla* high in the succession in the Moss Valley is unexpected, since this plant is characteristic of Zone E in South Wales."

Respecting the differentiation of Zones E and F, it is to be observed that in addition to the "index" species of her "Flora F", Dr. Dix [7] cited (pp. 806–7) as "noteworthy": *Neuropteris gigantea*, *N. pseudogigantea*, and *N. obliqua*, and as "familiar leaves" *Annularia microphylla* and *Asterophyllites equisetiformis*. She described (p. 805) the flora as "in certain respects" transitional between Floras E and G. Of the "additional" species in "Flora F", *N. gigantea* and *A. microphylla* had already been tabulated as diagnostic of Zone E and *N. obliqua* had been described (p. 800) as "dominant" in Zone D. *A. equisetiformis*, which is found throughout the Coal Measures, is valueless as an index fossil.

Of the species composing "Flora E", several "index" species are of little or no value in distinguishing Zone E from Zone F: *Lonchopteris rugosa* is too rare in Great Britain to be of wide stratigraphical value and is unknown from the Scottish coalfields; *Sphenophyllum myriophyllum*, *Annularia microphylla*, and *Neuropteris gigantea* show little difference in their frequency of occurrence in the two zones (if the number of available horizons is taken into consideration).

In regard to the species composing "Flora F", *Neuropteris tenuifolia*, though described [7] as often forming "the most conspicuous element" in Flora F, actually shows little difference in frequency in Zones E and F and the same is true of *N. obliqua* and *N. callosa* (the latter has already been noted to be merely a form of *N. tenuifolia*).

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[1] *N. callosa* is merely a form of *N. tenuifolia*. *Lepidodendron simile* would appear to be another example but it is an unsatisfactory species, being merely a form of *L. ophiurus* Brongt. See p. 349.

Reference to Table II (p. 349), which includes plants other than the "index" and "additional" species of Dr. Dix, shows that *Lepid. obovatum* has some slight value as characterizing Zone D (and Zone C) rather than higher divisions, that *L. ophiurus* is apparently commoner in Zones E and F than elsewhere,[1] and that *Sphen. cuneifolium*, *Sigillaria rugosa*, *Sphenopteris sauveuri*, and *S. trigonophylla* could, with more or less advantage, have been cited by Dr. Dix as "additional" species of "Flora E".

It will be seen that the criteria which distinguish Zones E and F from each other differ considerably from the "index" species of Floras E and F and that *Neuropteris tenuifolia*[2] is more or less common in both divisions. Zone F is to be distinguished from Zone E mainly by the negative criterion that the latter contains a number of species which appear to be absent from the former—*Lonchopteris rugosa*, *Sphenophyllum majus*, *Sphenopteris obtusiloba*, *S. dilatata*, *S. trifoliolata*, *S. laurenti*, *S. sauveuri*, *S. trigonophylla*, *Diplotmema furcatum*, *Dactylotheca plumosa*, *Alethopteris davreuxi*, *Sigillaria rugosa*, and *Lepidodendron obovatum*. None of these was found on more than three (of the eight) horizons in Zone E. The positive criterion consists in the relative frequencies of the species found in both Zones: *Neurop. gigantea*, *N. heterophylla*, and *Alethop. decurrens* are commoner in Zone E, while *Neurop. pseudogigantea* is commoner in Zone F. The species *Mariopteris muricata* cannot be used as a zonal form until the diagnosis is clarified: Dr. Dix [7] observed (p. 804) that in Zone E "The most common type of *Mariopteris* has been referred for the present to *M. muricata* (Schloth.), but it is probable that it includes at least two new species".

Lepidodendron simile Kidston MS. [9] represents fossils which have long been included under *L. lycopodioides* Sternb. (a form "tabulated" for Zone G),[3] and was discarded by Arber [1]; Professor Jongmans [11] has shown that both it and *L. lycopodioides* are merely *L. ophiurus* Brongt. Such being the case, neither *L. simile* nor *L. lycopodioides* is of primary zonal value. *Asolanus camptotaenia* occurs in Zone F and is apparently absent from Zone E but the present writer's experience is that this species is of little use as a diagnostic species in Great Britain.

It is evident that the divisions immediately below and above Zone E are mainly to be differentiated from it by negative criteria. On the evidence adduced the classification of the Yorkian strata of South Wales into three portions, as attempted in Dr. Dix's proposed classification, does not, therefore, seem practicable.

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[1] See, however, p. 349.

[2] Though *N. tenuifolia* is an "index" species of "Flora F", it is actually more characteristic of Zone G (the Staffordian Stage of the Kidston classification).

[3] Although *L. lycopodioides* is an "index" species for Zone G it is actually more common in Zone H.

It may here be said that the present writer suggested a division of the Yorkian Stage of Yorkshire—the type area—into an upper and a lower division on data somewhat similar to those used by Professor P. Bertrand [2, 3] in France. In Yorkshire the Lower Yorkian is distinguished by a preponderance of *Alethopteris lonchitica* and *Neuropteris gigantea* (typical form), while *Neuropteris obliqua*, though also having its maximum development in the division, is less characteristic. Occasional examples of the plants characterizing the underlying Lanarkian occur, but are unknown from the Upper Yorkian, i.e. *Neuropteris schlehani*, *Sphenopteris hoeninghausi*, *Sigillaria elegans*, etc. The Upper Yorkian can be recognized by the common occurrence of *Neuropteris tenuifolia* and *Sphenophyllum myriophyllum*, while the form known as *Neuropteris pseudogigantea* is found. *Lonchopteris bricei* is rare and is confined to the division. *Neuropteris grangeri*, *N. microphylla*, *Sigillaria elongata*, and *S. scutellata* are at their maximum, while *Sphenophyllum majus* does not occur in the Lower Yorkian. It may well be that these data could be applied to South Wales.

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Some Aspects of the Siluro-Devonian Boundary Problem.

By J. Shirley.

Introduction.

THE writer made a journey recently on the Continent to study the various facies of the Lower Devonian in connection with work on a fauna from New Zealand. Although not directly concerned with the lower limit of the Devonian System he gathered certain information regarding faunas near that boundary. This was especially a consequence of an invitation to the international excursion in May, 1937, arranged by the Prussian Geological Survey to discuss the Siluro-Devonian boundary and view a series of trenches at Hüinghausen, Westphalia, which, it was hoped, would expose the passage beds between these systems. The Prussian Geological Survey generously allowed the writer to collect somewhat later from these trenches. Professor Pruvost also invited the writer to examine the collections from Liévin at Lille, and later loaned a series of specimens for more detailed examination. For all these kindnesses the writer expresses his thanks. Mr. S. H. Straw has kindly read through the manuscript and made many valuable suggestions, and the writer had the benefit of discussion with Professor Richter of Frankfurt who also helped with material for comparison. To the authorities of the British Museum, the Museum of the Geological Survey, and the Sedgwick Museum the writer is indebted for the loan of, or access to, figured specimens. He also acknowledges a grant from the Royal Society which enabled him to make a journey on the Continent.

The Siluro-Devonian boundary has been the subject of many papers since these systems were erected a century ago. In Britain the " oscillation " of the boundary has not been great and a noticeable unity of opinion had become apparent in recent works except that King (1934) and Allan (1935) wished to draw the boundary at a higher level than had generally been accepted. On the Continent great difficulty has been experienced in correlating with the typical succession of the Welsh border. Two reasons have particularly contributed to the difficulties : the lack of a revision of the British Silurian faunas, especially the trilobites and brachiopods, and the change of facies from the marine Ludlow to the " continental " Old Red Sandstone. The first of these difficulties has led to the supposed recognition of " Silurian " elements in deposits on the Continent containing also " Devonian " forms ; this is especially a consequence of basing comparisons on figures in Davidson's Monograph of the Brachiopods, which are often restored or inaccurate. The second has led to a certain range of possibility of correlation which has tended to obscure the problem. It is also difficult to correlate between the Ardenne-Rhineland facies and those of the Harz and Bohemia. Only exact collection and comparison of the fossils, a monumental task in view of the present state of the nomenclature, can give the precision which is desirable to the correlation of these deposits. The correlation of strata should come actually before an attempt to draw a boundary which will be applicable over a wide area. The following notes are offered not as a solution of an exceedingly difficult problem but as a contribution to a better understanding of the comparison of strata about the boundary.

Comparison of the Succession at Liévin, N. France.

As a consequence of the change of facies about the Siluro-Devonian boundary in the type area of Shropshire, there has been a tendency to base discussions of the boundary, in so far as the marine facies is concerned, on the account of the succession at Liévin by Barrois, Pruvost, Dubois (1922, in Gosselet, Barrois, and others 1912–1922). These authors came to the conclusion that marine sedimentation was continuous in this area from the Middle Ludlow until well into the Gedinnian, which they took to be the lowest Devonian formation, and that the boundary between the two systems was best drawn at the horizon at which the greater part of the fauna had affinities with the younger Gedinnian faunas and the so-called Silurian elements played a minor role. This conclusion was based on two assumptions; the correlation of the Calcaire de Liévin, the lowest part of the succession containing *Dayia navicula*, with the *Dayia navicula* beds (Mocktree Shales) of Shropshire, and the correlation of the Grés de Pernes with a fish fauna of Old Red Sandstone affinities. Between these limits the Silurian fauna was supposed to give way gradually to a younger fauna and the boundary between the systems must be within this succession.

Let us re-examine the grounds for the correlation of part of this succession with the typical Shropshire succession. Stress will be laid on the articulate brachiopods and trilobites; other groups of fossils are too long-ranging or too little investigated to be of much use in precise correlation. The most important support for correlation with the Silurian succession was the occurrence of *Dayia navicula* in the upper part of the Calcaire de Liévin. At the time the Liévin Memoir was written it was thought that *D. navicula* was characteristic of the horizon of the Mocktree Shales immediatly above the Aymestry Limestone and that deposits containing it were to be directly correlated. But later work has shown that, in the Builth area and N. Wales, this species occurs as low as the zone of *Monograptus nilssoni* ranging through at least 3,000 feet of strata and the writer has found it associated with a typical Upper Ludlow fauna near Munslow, Shropshire. The stratigraphical value of *D. navicula* has considerably diminished.

The only other articulate brachiopod found in the Calcaire de Liévin is recorded as *Orthis edgelliana* Salter. Direct comparison with Salter's type specimens shows that the Liévin material cannot be referred to this species. Actually it belongs to the group of *Orthis* (*Fascicostella*) *gervillei* which is a characteristic fossil of the calcareous facies of the Lower Devonian.

The rest of the material under discussion which has been given names suggestive of correlation with the Ludlow of Shropshire will be listed in stratigraphical order :—

Calcaire d'Angres
  Stropheodonta simulans (McCoy) = *Stropheodonta triculta* Fuchs
  Stropheodonta semiglobosa (Davidson) = *Stropheodonta triculta* Fuchs
  Stropheodonta filosa (Sowerby) = *Stropheodonta triculta* Fuchs
  Stropheodonta corrugatella (Davidson) = *S.* aff. *ornatella* (Salter)
  Schuchertella pecten (Linnaeus). Not *S. pecten* of Davidson.
  Chonetes minima Sowerby. Not Sowerby's species
  Leptaena rhomboidalis (Wilckens)
  Orthis canaliculata Lindström = *Platyorthis* sp.
  Orthis lunata Sowerby = *Orthis fornicatimcurvata* Fuchs
  Rhynchonella borealis Von Buch ex Schlotheim
  Spirifer elevatus Dalman = *Spirifer* aff. *mercurii* Gosselet
  Glassia compressa (Sowerby) = *Nucleospira* sp.
  Meristella expectans (Barrande) = *Athyris* sp. cp. *Protathyris* Kozlowski 1929
  Atrypa reticularis Linnaeus
Couches de Drocourt
  Retzia bouchardi (Davidson) = *Trigeria* sp.

With the exception of the ubiquitous *L. rhomboidalis* and *A. reticularis* and possibly *R. borealis* there is not a single brachiopod in the corrected list which suggests comparison with the British Ludlow faunas. Mr. S. H. Straw pointed out to the writer that there is, furthermore, a complete absence of the characteristic British Ludlow brachiopods, a fact which, together with other anomalies of the correlation of the Liévin succession, he had noticed during his investigation of the Downtonian fauna of the Missenden boring (Straw, 1933).

With regard to the trilobites two pygidia from the Calcaire d'Angres were identified as *Calymene blumenbachi*. This cannot be upheld since the cephalon is necessary to specific identification. The genus ranges up to the Middle Devonian, therefore a generic reference to *Calymene* sp. has no stratigraphical significance in the present problem. *Acaste* from the Calcaire d'Angres and higher beds is under investigation by Professor Richter of Frankfurt.

Taking into account the above corrections, there is no part of the Liévin succession for which a case can be made out for direct comparison with the Ludlow rocks of the Welsh border or Shropshire, i.e. the typical Silurian area. One has only to place the lists of the Ludlow faunas published by Straw (1930, 1937) and Alexander (1936) alongside the corrected list of Liévin fossils to realize that the faunas of the two areas had little or nothing in common.

If the comparison of the Liévin succession with the typical succession fails certain other comparisons come more sharply into view. In the neighbourhood of Plettenberg in Westphalia have been discovered strata having much in common with the Gedinnian and also in the same area, *Dayia navicula* (Fuchs 1934). The discovery of the latter raised the question whether Silurian strata existed in this sequence. Recent investigations have proved the existence of Ordovician rocks overlain at an unknown stratigraphical distance by *Dayia* beds. These last are separated by a fault from the Hüinghausen Schichten, which contain a fauna of Gedinnian affinities (Richter, 1937). The contact between the *Dayia* beds and the strata above and below are not, as yet, exposed, but Professor Richter (1937, p. 306) has stated his belief that the *Dayia* beds are of Middle Ludlow age. The Hüinghausen Schichten are exposed in a series of trenches dug by the Prussian Geological Survey at Hüinghausen railway station and contain a faunal succession very similar to that of the Calcaire d'Angres and Couches de Drocourt at Liévin. It seems probable that the *Dayia* beds occupy a similar position, i.e. at the base of the Hüinghausen Schichten. Between them and the Ordovician may be an unconformity or older Silurian strata. In any case the parallelism between the successions at Hüinghausen and Liévin leaves little uncertainty as to their correlation.

Still further afield the succession in Poland offers some important resemblances to that of Liévin. The brachiopods have been magnificently monographed by Kozlowski (1929). The most obvious similarities consist in the occurrence of *Dayia navicula* in a band 15 mm. thick near the base of the succession followed shortly above by the first terebratulids, one of which, *Podolella rensselaeroides*, has considerable resemblance to *Rensselaeria primaeva* (Kozlowski, 1929, p. 235) from Liévin. Furthermore the fauna as a whole consists of a mixture of species having supposed Devonian or Silurian affinities. Kozlowski placed the whole succession provisionally in the Silurian. There is enough similarity to the Liévin succession to make comparison very suggestive.

Summarizing the results so far obtained it may be said that, of the three so-called Siluro-Devonian successions here considered, two of them, those of Liévin and Hüinghausen, are very similar and the third is more remote but still has much in common with the others. All three of these successions show little connection with the typical late Silurian of Shropshire. It becomes necessary to inquire how these several successions and faunas were related to one another both palaeogeographically and in time.

It has been stated that stress should be laid on the newer elements in a fauna rather than on survivals from lower horizons. The following list gives those forms occurring in the supposed Silurian faunas of Liévin of aspect more typically Devonian than the Ludlow faunas of Shropshire. *Fascicostella*, *Platyorthis*, *Rensselaerina*, *Trigeria*, *Athyris*, *Ambocoelia*, *Nucleospira* (of the flat type), *Spirifer* of the *mercurii* type. One of these elements, *Fascicostella*, is already present in the Calcaire de Liévin with *Dayia navicula*; whilst *Platyorthis*, *Proschizophoria*, *Rensselaerina*, *Athyris*, *Ambocoelia*, *Nucleospira* and *Spirifer mercurii* are present in the Calcaire d'Angres, *Trigeria* begins in the Couches de Drocourt. On the evidence, therefore, of the newer elements the whole succession would be regarded as younger than the typical Ludlow which does not contain any of them. It is unfortunate that neither the Liévin, Hüinghausen nor Polish successions go down into strata whose Silurian age would not be in doubt. The fact that they do not may be significant.

The authors of the Liévin Memoir came to the conclusion that the boundary between the Devonian and Silurian should be drawn below the Schistes de Mericourt. The reasons for this choice were carefully argued but the principal one was that in the Schistes de Mericourt the fauna became predominantly Devonian in character although it was admitted that there was a regular transition between the " Silurian " and " Devonian ". It has been shown above that many of the fossils were incorrectly referred to British Ludlow species and that the revised naming gives a distinctly younger appearance to the age of the fauna. Furthermore, as has been already stated, the fauna of the British Upper Ludlow does not appear at Liévin, Hüinghausen or in Poland, in fact, this fauna seems to have a limited geographical distribution. It is a pertinent question whether a purely palaeontological boundary can be drawn in the Liévin succession except possibly below the Psammites de Liévin where fish remains give a distinctive character to the fauna, and the marine type of sediment gives way to the " continental ". The table of distribution of fossils (Barrois, etc., 1922, tab. 7) shows clearly that there is no break in the palaeontological succession except where the facies changes directly below the Psammites de Liévin. The conclusion is that, if there is a palaeontological break of wide significance, it must be sought either below the *Dayia* beds (Calcaire de Liévin) or still higher in the succession than the Psammites de Liévin.

With regard to correlation with the British succession there are three possibilities :—

(1) That the *Dayia* beds of Liévin are equivalent to the Middle Ludlow and that the succeeding strata are to be correlated with Upper Ludlow and Downtonian. This is the view put forward by the authors of the Liévin Memoir.

(2) That the *Dayia* beds of Liévin are equivalent to the Middle Ludlow but are separated from the succeeding strata by a non-sequence. These strata would then be placed in the Gedinnian, there being no representative of the Upper Ludlow.

(3) That the whole succession is post-Ludlow.

With regard to the first possibility, there are no direct supports for this correlation with the exception of the presence of *Dayia navicula* which is now known to be much longer ranging than was formerly believed and there is no *a priori* reason why it should not have persisted into the post-Ludlow. If the correlation proposed by the authors of the Liévin Memoir is correct then there must have been a barrier which almost completely prevented migration between the Welsh area and N. France-Westphalia since the other common fossils of the British Ludlovian do not occur at Liévin. The sediments of the different areas are so similar that it is unlikely that facies differences could account for the dissimilar faunas.

The second possibility appears to be ruled out for lack of evidence of a break in sedimentation between the Calcaire de Liévin and the Calcaire d'Angres, although it should be borne in mind that the knowledge of the succession comes from boreholes and shaft sections, not from the mapping of exposed rocks. There is very little difference between these two so-called limestones.

The third possibility is supported by the presence throughout the succession of genera typically Devonian. It is tempting to suppose that the most important break in the succession will be found below the Calcaire de Liévin or the *Dayia* beds at Hüinghausen, and that the whole succession is post-Ludlow. Such a correlation removes the difficulty of explaining the presence of "Devonian" forms in a fauna supposed to be contemporaneous with the typical Ludlow in which such forms are completely absent. It also removes the difficulty of explaining an absolutely continuous succession in one area whilst a comparatively short distance away the Gedinnian lies unconformably on folded graptolitic Lower Ludlow and oversteps down to the Cambrian.

The proof of the stratigraphical position of the Liévin succession will come only from a comparative study of some group of fossils which is known to range from definite Ludlow deposits into the higher Gedinnian and which occurs at Liévin; the strophomenids seem to offer reasonable chances of success in such a study. Until such a series has been investigated the correlation of the Liévin succession cannot be finally settled.

REMARKS ON CERTAIN SPECIES OF ARTICULATE BRACHIOPODS OCCURRING AT LIÉVIN, N. FRANCE.

The following remarks are intended only to make clearer the comparisons of certain species of brachiopods from Liévin with their supposed Silurian representatives. Where possible already figured specimens have been used and the registered numbers in the British Museum (Natural History) or the Museum of the Geological Survey are given. This choice of specimens has been made without prejudice to the possible choosing of Rectotypes of the several species mentioned.

Orthis lunata Sowerby.

Liévin Memoir, pp. 77–79, pl. 11, figs. 4–12.

The authors of the Liévin Memoir regarded *Orthis lunata* Sowerby (1839, p. 611, pl. 3, fig. 12*d*, pl. 5, fig. 15) and *O. orbicularis* Sowerby (1839, p. 611, pl. 5, fig. 16) as being synonymous. Actually these species are separate and distinct. Furthermore, they have somewhat different time ranges in the Ludlow rocks of the Welsh borderland, *O. orbicularis* appearing earlier than *O. lunata*.

The Liévin material is identical with *O. fornicatimcurvata* Fuchs (1919, pp. 58–61, pl. 5, figs. 1–6, 10, pl. 6, fig. 1*a*) which occurs in the Hüinghausen Schichten. Compared with *O. orbicularis*, *O. fornicatimcurvata* has a more convex dorsal valve, a smaller cardinal process more deeply sunk between the crural bases, muscle impressions of different shape and coarser ornament. It might well be that *O. fornicatimcurvata* was derived from *O. orbicularis*.

Orthis canaliculata Lindström.

Liévin Memoir, pp. 79–80, pl. 11, figs. 13–20.
Davidson, 1869, pl. 27, fig. 13. (British Museum B 13459.)

Davidson's specimen, a dorsal valve showing the interior, differs from that of the Liévin species in having spreading crura, a cardinal process completely divided into two parts unsupported by a median ridge, denticulate dental sockets, and more rounded muscle impressions.

Davidson's *O. basalis*, placed in the synonymy of *O. canaliculata* in the Liévin Memoir, does not belong to the same species as Davidson's *O. canaliculata* nor to the same species as the Liévin material, from which it differs in having more spreading crura and more rounded muscle impressions.

The Liévin species is a typical *Platyorthis* (Schuchert and Cooper, 1931, p. 246 ; 1932, pp. 135–136, pl. 19, figs. 18–19, 23–24, 27-29, 31) in its dorsal structures, i.e. in possessing an almost circular outline, a heavy projecting cardinal process, crura which are almost parallel, and a radial ornament on the inside edge approaching very near to the umbo. Exactly the same type of structure and ornament is shown by dorsal valves of *Orthis circularis* from the Middle Siegenian of Seifen, Westerwald.

Platyorthis is a Devonian genus except that Schuchert and Cooper (1932, p. 135) include *Dalmanella cimex* Kozlowski (1929, pp. 71–74, pl. 2, figs. 17–23) in the list of species belonging to this genus ; this is possibly not justified.

Orthis edgelliana Salter Mss. Davidson.

Liévin Memoir, p. 80, pl. 11, figs. 21–22.
Davidson, 1869, pl. 32, figs. 1–2. (Geological Survey Museum 13209, 13211.)

The Liévin specimens differ from *O. edgelliana* in having a more marked dorsal sinus, a flatter dorsal valve, much more fasciculate ribbing (Davidson's figures are somewhat misleading in this respect) and the number of primary ribs is less numerous: 10 against 14 or 16.

The Liévin material belongs to the group of *Orthis* (*Fascicostella*) *gervillei* (Defrance) (see Oehlert, 1886, p. 44, pl. 4, figs. 45–55), which is somewhat variable in the development of the sinus. The number of primary ribs is the same in the Liévin specimens and typical *O. gervillei*. The specimens show no internal features, in which *O. gervillei* differs considerably from *O. edgelliana*.

O. gervillei is widely distributed in Lower Devonian rocks of the Bohemian or calcareous facies with the exception of a single specimen recorded by Kozlowski (1929, pp. 70–71, pl. 1, fig. 32) from the Étage de Borszczow which he places in the Upper Ludlow although it contains elements of Devonian affinities.

Stropheodonta corrugatella (Davidson).

Liévin Memoir, pp. 85–86, pl. 12, figs. 12–14.
Davidson, 1871, pl. 41, fig. 12. (British Museum B 13606.)

Davidson's specimen is from the Llandeilo of Balcletchie, Ayrshire. It is not a stropheodontid.

The Liévin material is typical of the group of *Stropheodonta ornatella* both as regards its ornament and internal features. This group is known to range at least into the Upper Gedinnian (Asselberghs, 1930, pp. 29–30, pl. 3, figs. 1, 7). It is not, however, to be referred to *Douvillina* as Asselberghs suggests.

Stropheodonta semiglobosa (Davidson).

Liévin Memoir, p. 83, pl. 12, figs. 10–11.

Stropheodonta filosa (Sowerby).

Liévin Memoir, pp. 83–84, pl. 12, figs. 6–9.

Stropheodonta simulans (McCoy).

Liévin Memoir, pp. 84–85, pl. 12, figs. 15–19.

All these specimens belong to one and the same species: the differences are due to different development of ornament on different parts of the shell and to different preservations. Comparison of specimens shows, as Asselberghs (1930, pp. 26–29) demonstrated for *Stropheodonta subarachnoidea* (Liévin Memoir, pp. 155–157, pl. 17, figs. 19–21), that they belong to *Stropheodonta triculta* Fuchs (1919, p. 61, pl. 5, figs. 8, 10).

Strophomena imbrex var. *semiglobosa* Davidson and *Leptaena* (*Strophomena*) *simulans* McCoy are Ordovician shells, neither of which have a denticulate hinge.

The original specimen of "*Orthis*" *filosa* Sowerby (1839, p. 630, pl. 13, fig. 12), Geological Survey Museum 6644, is a poorly preserved dorsal valve, but it is quite certain that this should not be referred to the same species as *Stropheodonta triculta* Fuchs.

Chonetes minima (Sowerby).

Liévin Memoir, pp. 86–87, pl. 11, figs. 23–25.
Sowerby, 1839, p. 629, pl. 13, fig. 4. (Geological Survey Museum 6639.)

The Liévin specimens differ from Sowerby's specimen in having more numerous ribs at the same size. At 2·5 mm. from the umbo the type has about 30 ribs, the Liévin specimen of figure 24 has at least 40; at 4·0 mm. from the umbo the type has about 35 ribs, the Liévin specimen of figure 25 at the same size has at least 45.

Glassia compressa (Sowerby).

Liévin Memoir, p. 148, pl. 13, figs. 43–44.
Sowerby, 1839, p. 629, pl. 13, fig. 5. (Geological Survey Museum 6625.)

The Liévin specimens belong to the genus *Nucleospira;* the specimen figured as fig. 43 shows the typical striate-flabellate ventral muscle impressions and the median internal ridge of this genus. The Devonian species of *Nucleospira* are of the same type as the Liévin specimens, i.e. with flat, rather lens-shaped valves. The Silurian species of the genus are generally globose.

Sowerby's specimen of *Glassia compressa* is a complete shell showing only external features, but it certainly does not belong to *Nucleospira* since it does not show the characteristic median depression of both valves.

Spirifer elevatus Dalman.

Liévin Memoir, pp. 88–89, pl. 13, figs. 4–10.
Davidson, 1867, pl. 10, fig. 7. (British Museum Tablet B 5208.)

Davidson's specimens do not reach the size of the Liévin material, they have fewer ribs and a much higher area. The Liévin material is distinguished by the lowness of the area relative to the length of the hinge-line.

The Liévin specimens give the impression of being much more "advanced" than the Wenlock and Ludlow *Spirifer elevatus* and are to be referred rather to *Spirifer mercurii.* The groups of *Spirifer* centred on *S. elevatus* Dalman, *S. elevatus* mut. (Upper Ludlow form), *S. mercurii* Gosselet, and *S. inchoans* Barrande deserve more careful study than they have hitherto received.

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Problems of Ammonite Nomenclature.

2. SCHLOTHEIM'S TYPES OF *AMMONITES CAPRICORNUS*.

By L. F. SPATH.

IN my *Catalogue of the Ammonites of the Liassic Family Liparoceratidae in the British Museum*, now in press, I was obliged to discuss one of the commonest and most widely quoted of ammonite species, namely Schlotheim's *Amm. capricornus*.[1] Clearly it was impossible to ignore this species, merely because "its precise application was not known".[2] I am not only in agreement with H. Douvillé[3] that it is of capital importance always to respect a specific [trivial] name, however much generic names may be changed, but among the foreign ammonites in the British Museum there were several different forms labelled *Amm.*

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[1] *Petrefactenkunde*, viii, Mollusciten, 1820, p. 71 (at first named *Amm. spatosus*—a *nomen nudum*—in "Beiträge zur Naturgeschichte der Versteinerungen, etc.," *Leonhard's Taschenbuch*, vii, 1813, 101).

[2] Trueman, "Evolution of the Liparoceratidae," *Quart. Journ. Geol. Soc.*, lxxiv, 1919, 275.

[3] *C.R. Congrès géol. internat.*, sess. 2, Bologna, 1881 (1882), p. 608.

capricornus; and an attempt had to be made to identify the species. Luckily the Schlotheim collection in the Geological and Palaeontological Museum of Berlin University still retained the original types of *Amm. capricornus*, with Schlotheim's MS. labels; and by the kindness of Dr. W. O. Dietrich I have been able to examine them. I am figuring four of the syntypes of Schlotheim's species and I have selected one of them as the lectotype (plate xxiii, fig. 1). It may seem curious that a species which had been created in 1820, whose name has been in common use for over a century, and whose types were so accessible, had not before been put on a safe footing; but the only palaeontologist who re-examined Schlotheim's material (since Schloenbach, 1863) with a view to selecting a type seems to have been the author of a dissertation which was never completed.[1]

It is intended in the present note to discuss the legality of my selection of a type, for it is rather late in the day to stabilize a species that has been dealt with by previous authors on so many occasions. First I may point out that, although a Committee of Palaeontological Nomenclature, as long ago as 1882,[2] proposed a rule to delay the recognition of a species until it was figured as well as described, a recent opinion by the International Commission on Zoological Nomenclature[3] does not favour the automatic rejection of a species simply because it was not figured. It is clear that a bad illustration, even from a photograph, may be no more helpful than a bad description; and, in accordance with Article 25 (*a*) of the Code, *Amm. capricornus* is a valid species, although it was not figured by Schlotheim and although the description may be held to be "inadequate". In reality the description was quite sufficient, for, while part of it also applies to *Amm. maculatus* Young and Bird (established in 1822) and to *Amm. lataecosta* J. Sowerby (dating from 1827), the presence of angulate ribs on the periphery clearly characterized *Amm. capricornus.*

Schlotheim recorded nine examples of his species, three of which were later separated from *A. capricornus* by Schloenbach[4] (falling within the genus *Oistoceras*, as now understood), while I have been able to recognize two more as species of *Acanthopleuroceras* (*maugenesti-quadratum* group) of an earlier horizon. But since these were already marked by Schlotheim as varieties, there can be no doubt as to the authenticity of the four syntypes I am figuring.

A more serious problem is the synonymy given by Schlotheim. He cites, first, *Amm. bisulcata* Bosc,[5] which, however, was distinctly characterized as having a sharp keel, accompanied by a groove on each side, and which is therefore not in the least comparable to *Amm. capricornus*. Lister's [1] form, also cited, is probably a *Pleuroceras* (group of *Amm. spinatus* Bruguière), as is the ammonite represented in Mylius's [2] striking engraving, and they have as little to do with *Amm. capricornus* as the large form illustrated by Baier.[3] There remain, first, the ammonite figured by Bourguet [4] which may be a capricorn, although, if so, it is drawn rather inaccurately; and finally Knorr's [5] figure which is undoubtedly the best, and does represent one of the true capricorns for which Schlotheim intended his species, although it is not *Amm. capricornus* in the restricted sense. Now Oppel [6] in 1856, and Quenstedt [7] in 1883, accepted Knorr's figure as representing the typical, or rather the original, *Amm. capricornus*; and in 1936 I [8] still interpreted Schlotheim's species by what I called Knorr's well-recognizable figure. But not only did Schlotheim *not* link his species with any form cited in the synonymy, specially referring to these as only "appearing to belong" to *Amm. capricornus*, and therefore being doubtful, but Knorr's figure actually represents a serpenticone form that is not included among Schlotheim's type material. That is to say, the resemblance is only general, not specific; and since no peripheral view was given by Knorr, it is doubtful whether the example shows the most characteristic feature of *Amm. capricornus*, namely the ventral chevrons. Knorr's form (which is probably lost) thus does not automatically become the type of Schlotheim's species.

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[1] Personal information kindly given by Professor Dr. R. Brinkmann, Geologisches Staatsinstitut, Hamburg.

[2] *C.R. Congrès géol. internat.*, sess. 2, Bologna, 1881 (1882), p. 594.

[3] *Smithsonian Miscellaneous Collections*, 73, No. 8, 1936, 5–22 (Opinion 126).

[4] "Über den Eisenstein des mittleren Lias im N.W. Deutschland, etc.," *Zeit. Deutsch. Geol. Ges.*, xv (1863), 520.

[5] *Histoire Naturelle des Coquilles*, v (1802), 176.

The first author to figure an *Amm. capricornus* was Zieten,[9] but he not only unjustifiably transferred the name to quite a different species and one from a much lower horizon in the Lower Lias, but also made a mistake in the locality, and started a misidentification which was perpetuated by Quenstedt to the last. Since Schloenbach, however, in 1863, re-examined Schlotheim's types and stated that *Amm. capricornus* was the same as Quenstedt's *Amm. maculatus*, but not his *Amm. capricornus*, all other German authors recognized Zieten's and Quenstedt's error and refused to accept the transposition of the name. In France, meanwhile, d'Orbigny,[10] who probably was partly misled by de Haan and Zieten, identified *Amm. capricornus* with Sowerby's *Amm. planicosta* dating from 1814.

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[1] *Historiae animalium angliae*, 1678, pl. vi, fig. 3.

[2] *Memorabilium Saxoniae Subterraneae*, pt. 2, 1718, p. 53.

[3] *Oryctographia norica*, etc., suppl. 1757, pl. xiii, figs. 1–2.

[4] *Traité des Petrifications*, 1742, p. 71, pl. xli, fig. 271.

[5] In Knorr & Walch, *Naturgeschichte der Versteinerungen*, ii, pt. 1, 1768–1771, pl. i, fig. 5.

[6] "Die Juraformation Englands, Frankreichs und des S.W.-Deutschlands," *Württ. naturwiss. Jahresh.*, x, 1856, 278.

[7] *Die Ammoniten des Schwäbischen Jura*, i, Der Schwarze Jura, 1883, 155.

[8] "The Ammonites of the Green Ammonite Beds of Dorset," *Quart. Journ. Geol. Soc.*, xcii, 1936, 450.

[9] *Die Versteinerungen Württembergs*, 1830, p. 6, pl. iv, fig. 8.

[10] *Pal. Française, Terr. Jurass.*, i, 1844, 242, pl. lxv.

Since he characterized the species as always occurring in association with *Amm. margaritatus*, it was easy to see that d'Orbigny actually had in mind Schlotheim's species, or at least a true capricorn, at the same time, however, giving it the wrong name and probably confusing with it forms of the rather micromorph *planicosta* group (e.g. d'Orbigny's fig. 4). But the larger example figured by d'Orbigny figs. 1–2), again, is not the *Amm. capricornus* of Schlotheim, but the *Amm. lataecosta* of Sowerby. It must be remembered that the latter species was also misinterpreted by d'Orbigny, being considered identical with *Amm. brevispina*.

D'Orbigny's error was soon discovered, and, by the time Wright[1] discussed *Amm. capricornus*, all authors agreed that d'Orbigny's *Amm. planicosta* was not Sowerby's species. But Wright, copying a figure from Chenu[2] which was a reduced woodcut of d'Orbigny's illustration of his *Amm. planicosta*, considered this to represent *Amm. capricornus*. Subsequently Buckman,[3] in 1911, wrote that *Amm. planicosta* d'Orbigny recognized in Waagen's time as *Amm. capricornus*, was a good figure to select for *Amm. capricornus*, auctt. This selection, at first, caused me to doubt the validity of my own choice of a lectotype for *Amm. capricornus*.

It seems clear, however, that Buckman did not select a type for the species *Amm. capricornus* Schlotheim. First, he stated that it was very doubtful what exactly was Schlotheim's species and thus, rightly or wrongly, left it alone. What he was concerned with was the designation of a lectotype for the genus *Aegoceras*, and for this he chose "*Amm. capricornus*, Waagen & auctt."[4] from among the genosyntypes on the score of tautonymy (compare Article 30, I, *d*, and Recommendation III, i). Buckman's choice is not invalidated by the fact that he interpreted the species by d'Orbigny's figure which was what Waagen and other authors were believed by Buckman to have taken as *Amm. capricornus*. But d'Orbigny's form (which in my opinion falls within *Amm. lataecosta* J. Sowerby) does not even agree with Schlotheim's original description of *Amm. capricornus*, not having the characteristic angular ventral ribbing, at least on the outer whorl. Trueman in 1919, by not using the name *Amm. capricornus* Schlotheim, and by citing *Amm. planicosta* d'Orbigny as genolectotype of *Aegoceras*, may be taken to have confirmed the view here expressed that Buckman did not stabilize Schlotheim's species. But Trueman mentioned "*A. capricornus* Hyatt" (as the genotype of *Amblycoceras*) without, however, suggesting that the figure (copied from previous text-books by Zittel) represented Schlotheim's species. In fact, since *Amm. capricornus* was already indicated as the type of *Aegoceras*, it was clear that " *A. capricornus* Hyatt " could not be specifically identical with Schlotheim's species yet belong to a different genus. Moreover Zittel's form can now be shown to be both specifically and generically distinct from the syntypes in Schlotheim's collection (being a species of *Oistoceras*), though it answered the original description much better than did d'Orbigny's form.

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[1] *Monograph of the Lias Ammonites* (Pal. Soc.), pt. 5, 1882, p. 369.

[2] *Manuel de Conchyliologie*, etc., Paris, 1859, p. 87, text-fig. 375.

[3] *Yorkshire Type Ammonites*, i, 1911, iii.

[4] Waagen did not assign an author's name to *Amm. capricornus*, when listing it as a syntype of *Aegoceras*, but it is clear from his previous work that he had Schlotheim's species in mind.

I may add that, since *Amm. capricornus* is close to *Amm. lataecosta*, and this again to *Amm. hybrida* d'Orbigny (refigured in my Catalogue), they all fall within the genus *Androgynoceras* Hyatt, 1867, which has priority over *Aegoceras* Waagen, 1869. *Amblycoceras* Hyatt, 1900, was meant to replace *Microceras* Hyatt, 1867 (pre-occupied), and is a synonym of *Aegoceras* (misinterpreted by Hyatt) ; but as emended by Buckman (1915) and Trueman (1919) " *Amblycoceras* " falls within *Oistoceras* Buckman, 1911.

Petrological Studies in the Harlech Grit Series of Merionethshire. I. Metamorphic Changes in the Mudstones of the Manganese Shale Group.

By Austin William Woodland, Department of Geology, Queen's University, Belfast.

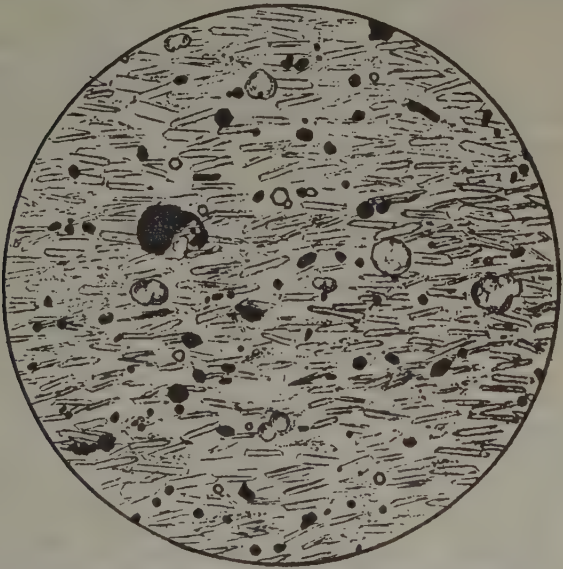
I. INTRODUCTION.

THE mudstones of the Manganese Shale Group are very similar in their characters throughout, but in the present work, greatest stress is laid upon the mudstones of one horizon—the *Bluestone*. This is about 5 ft. 6 in. thick, and occurs immediately above the manganese-ore band, which is 30 feet above the base of the group. From this horizon special metamorphic derivatives of the normal mudstones have been obtained from one locality—the lower end of the workings of the Hendre Mines on the north-west slopes of Moelfre, about 2¾ miles east 15 degrees south of the village of Llanbedr. There is no doubt that the types described belong to this one horizon, which is everywhere else remarkable for its uniformity of character. They always follow immediately on the manganese-ore band in the normal manner, without break, and their relationships with the succeeding strata are apparently the same as with the normal rocks. Also, with the exception of the calcite-bearing rock (p. 372), all the rock types are identical chemically.

II. THE NORMAL MUDSTONES.

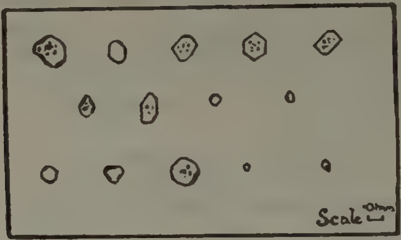
Macroscopic Characters.—A fine-grained blue-grey mudstone, well-bedded with a very regular thinly striped bedding, the individual laminae varying from 0·5 mm. to 1·5 mm. There is no fissility along the junctions of these layers and the whole forms a compact mudstone. The lamination consists of an alternation of darker and lighter blue-grey materials, and the junctions between successive laminae are parallel plane surfaces.

Microscopic Characters.—The darker bands consist of a very fine-grained intergrowth of detrital quartz fragments, lath-shaped crystals of chlorite and sericite, with not abundant colourless and reddish-brown garnets, allothigenous and authigenous magnetite, and dialogite (manganese carbonate). The quartz, often presenting a mosaic intergrowth, has a grain size of 0·005 mm. to 0·015 mm., averaging 0·010 mm. The chlorite and sericite occur in crystals varying from 0·015 mm. to 0·030 mm. long and from 0·002 mm. to 0·007 mm. wide. The chlorite has a pale though bright green colour, and a distinct pleochroism from almost colourless or very pale green to bright green. The sericite is almost colourless and is distinguished by its higher birefringence. The laths are often orientated in a definite plane, which may be at an angle to the bedding (denoting an incipient cleavage), see Text-fig 1. The colourless garnets are nearly always present; they occur as six-sided euhedral crystals, 0·005 mm. to 0·018 mm. in diameter. With them occurs a reddish-brown variety which, varying from 0·002 mm.

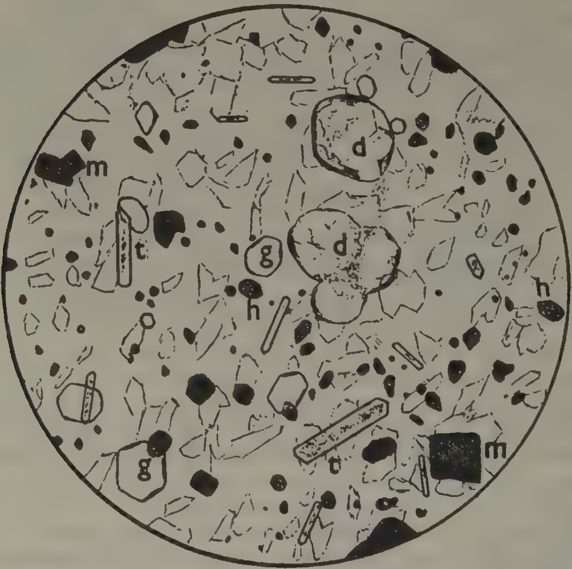


TEXT-FIG. 1.—Normal Mudstone; St. John's Church, Barmouth. Colourless and reddish-brown garnets, globules of dialogite, and magnetite set in a matrix of intergrown quartz, chlorite, and sericite. Magnification × 375 diams.

to 0·035 mm., on the whole tends to be slightly larger than the colourless variety. By virtue of their high refractive index, both varieties stand out very clearly from the matrix. They frequently contain minute crystalline inclusions, usually concentrated in the centres. The ratio of colourless to coloured garnet present varies



TEXT-FIG. 2.—Mode of occurrence of the minute authigenous garnets.



TEXT-FIG. 3.—Mudstone with tourmaline, lower portion of "Bluestone" east side of Diphwys. *t*, tourmaline; *g*, colourless garnet; *h*, reddish brown garnet; *d*, dialogite globules; *m*, magnetite. Matrix: quartz chlorite, and sericite. Magnification × 375 diams.

considerably. The dialogites occurs as small equidimensional globula masses, 0·015 mm. to 0·020 mm. which, however, exhibit nc characters that suggest either a radial or a concentric structure The refractive index has a large range, the upper limit being high and the globules often stand out as clearly as the garnets. The birefringence is extreme, giving very bright polarization colours.

The paler bands are characterized solely by greater amounts of dialogite, some of the palest being composed predominantly of it. The garnets are not as abundant relatively and there is a marked decrease in the proportion of the reddish variety. This variation in the amount of dialogite possibly reflects a seasonal variation in the amount of carbonate being precipitated.

Many of the mudstones, without differing in any way from the above, develop tourmaline. This occurs in minute euhedral crystals, 0·020 mm. to 0·035 mm. long and from 0·005 mm. to 0·015 mm. wide. The crystals are prismatic with perfectly developed rhombohedral and basal parting terminations, rare crystals being hemimorphic. The pleochroism is strong with $x < z$.

x = pale yellowish-green, z = greenish-brown

Minute transparent and opaque inclusions, too small to be recognized, are present. They form only a very small proportion of the rock (Text-fig. 3). On account of their euhedralism, their approximate equal size, and their uniformity in specie they are regarded as being authigenous.

Authigenous magnetites in good octahedra are always present and are sometimes developed on a large scale. They vary from 0·020 mm. to 0·040 mm., and the larger crystals are occasionally surrounded by narrow zones of green chlorite.

III. The Metamorphic Types of the Hendre Locality.

(*a*) *The biotite-chlorite-spessartite-dialogite-quartz mudstone.*—Macroscopically a striped, blue-grey mudstone, not distinguishable from the normal mudstone, except possibly by a tendency to a slightly darker colour. Microscopically the rock consists of a fine-grained intergrowth of quartz, lath-shaped chlorite, colourless and reddish-brown garnets, magnetite, and dialogite, all of the same mineralogical characters and with the same relations as in the normal mudstone, and in addition a greenish-brown mica. This occurs in irregularly dispersed aggregates of crystals varying from 0·020 mm. to 0·080 mm., with an average of 0·030 mm. to 0·040 mm. The individuals are sometimes platy fragments devoid of all shape, but they usually show good tabular crystals with frayed and broken edges. The tabular crystals are elongated parallel to the direction of the good edges, and they have a length : breadth ratio varying from 5 : 2 to 3 : 2. The cleavage is perfect, though not abundantly developed, in one direction, parallel to the length of the crystal. The mineral is greenish-brown and displays a well-marked pleochroism, with greatest adsorption parallel to the cleavage. The change of colour is from light greenish-brown or brownish-green to an intense brown. The refractive index varies from slightly above to distinctly above that of quartz, and the maximum birefringence is approximately 0·040, the interference colours ranging up to red of the second order. Extinction is parallel to the cleavage traces, and the crystals are orientated with the cleavages parallel to the slower ray. Twinning is doubtful parallel to the cleavage. The interference figure is biaxial and negative. The axial angle 2V is small and the dispersion weak. It is thus undoubtedly a member of the biotite system.

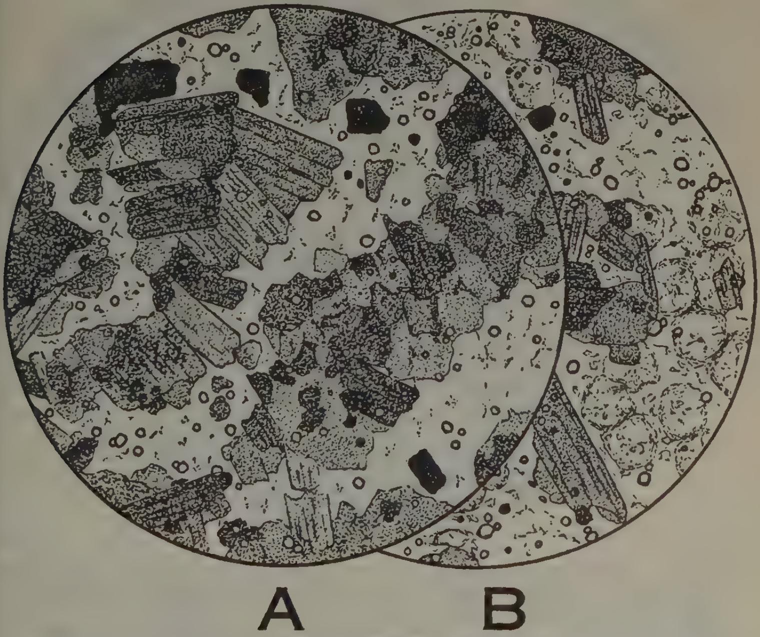
The crystals are orientated haphazardly with a slight tendency for the majority to be in planes approaching parallelism with the bedding. They are closely intergrown with the chlorite and there appears to be actual transition of one into the other by the chlorite becoming darker in colour and developing a higher birefringence. Some of the tabular crystals even appear to consist partly of chlorite and partly of biotite with no sharp line of division between them. The amount of biotite actually developed varies in different specimens, and also in different laminae of the same specimen. In the paler bands the amount of biotite is distinctly less than in the darker, in some of which it may form as much as 50 per cent of the band, and be the only ferro-magnesian mineral developed (see Text-fig. 4). If dialogite be absent some of the bands may consist wholly of biotite and quartz with scattered minute garnets and magnetite.

(*b*) *The garnet-quartz rock.*—All the specimens were obtained from the lower end of the Hendre workings; similar rocks were, however, observed, though not so well developed, in the middle region of the Cwm Mawr workings, north of Cwm Bychan.

Macroscopically they have a superficial resemblance to the normal mudstones, inasmuch that they, too, possess the peculiar regular thinly striped bedding. Whereas the normal rock is relatively soft and friable, this type is much more compact and is very hard and flinty, being much harder than a knife. It has an uneven, semi-conchoidal fracture and there is no cleavage. The rock has a very "hornstone"-like character. It is generally lighter in colour than the normal mudstone, and consists of alternations of very pale greenish-grey and somewhat darker greenish-grey bands, some having a slightly purplish tinge. The bedding, on the whole, is rather regular, but occasionally the beds show signs of much crumpling due to lateral pressure. This crumpling is sometimes brought out very beautifully by differential weathering of the layers. Some specimens show a slight tendency to disharmonic folding, with bands which are well folded succeeded by beds which are not so intensely crumpled. Occasional lenticular masses occur, which are darker and more siliceous; they are especially developed pinched out among the crumpled portion.

Under the microscope the rock consists essentially of colourless garnet and quartz. The garnets vary in size from 0·004 mm. to 0·014 mm., i.e. they are of the same size as the ordinary colourless garnets from the less altered mudstone. Throughout the whole rock this garnet makes up by far the predominant portion of the rock. In the paler bands it comprises approximately 90 per cent, the rest being made up chiefly of quartz. In the slightly darker bands the amount of garnet falls to about 80 per cent. In these, in addition to quartz, small amounts of intergrown chlorite are developed. This is a very pale green, only very feebly pleochroic type, which occurs in slender fibres and laths and on account of its paleness is not easy to distinguish. It gives ultra-blue polarization colours and may be related to penninite.

The quartz has been recrystallized and bears an interstitial relationship to the garnet. Owing to the preponderance of garnet the major portion of the field remains dark when it is revolved between crossed nicols, and the area of isotropy tends to be somewhat greater in the paler than in the darker bands. Magnetite occurs sporadically; it does not appear to be as euhedral as in the normal mudstones, and marginal solution of the original crystals is suggested.

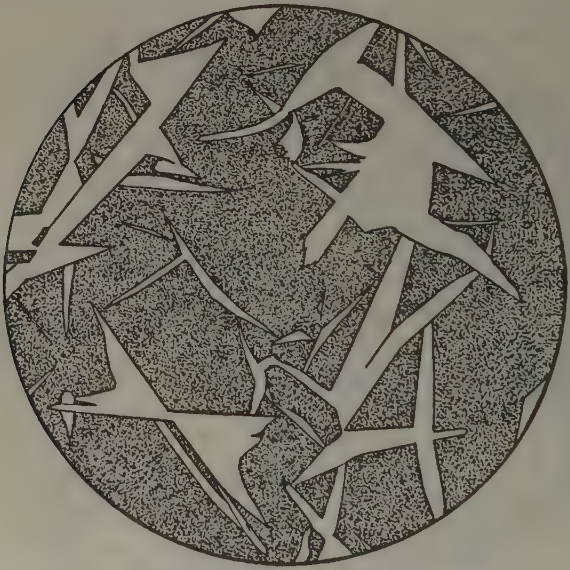


TEXT-FIG. 4.—Biotite-chlorite-spessartite-dialogite-quartz mudstone, Hendre Mines, north-west slopes of Moelfre. A. The darker bands with abundant biotite; the accompanying minerals are quartz, colourless and reddish-brown garnets, and magnetite. B. Paler bands with less biotite and a relative abundance of globular granules of dialogite. Magnification × 375 diams.

The darker irregular lenticular developments consist of a mosaic of regenerated quartz with relatively abundant chlorite, recrystallized dialogite and thinly dispersed colourless garnet. The constituents are closely intergrown and have a relatively large "grain"; approximately 0·1 mm. Good rhombohedral cleavage is developed among the regenerated dialogite.

(c) *The calcite-muscovite-chlorite mudstone.*—The rocks concerned were noted in one locality only—in the open trench workings in the lowest of the Hendre Mines, ¼ mile south-east of Cil Cychwyn Farm.

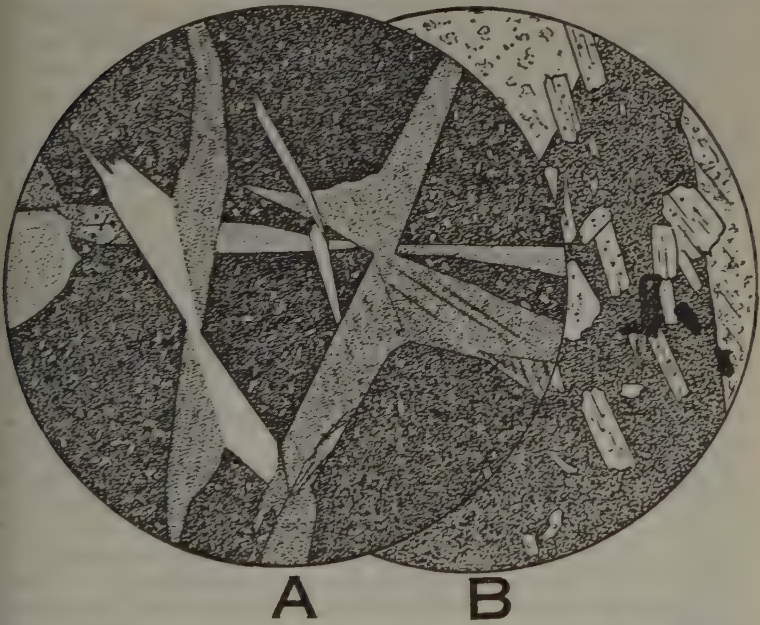
In colour the rock is a dark greyish-green, the intensity varying slightly in different bands. The original thinly striped character is still discernible, though recrystallization has made it less obvious. The rock now consists of an alternation of dark greenish-grey bands and lighter greyish-green bands. The latter are frequently very hard and very compact, and are similar to the garnet-quartz rock. The darker bands are not so hard, and they have a coarser and less compact nature. Usually throughout these is developed coarsely crystalline mangancalcite. These crystals are frequently well developed in bands coincident with the bedding of the rock, the bands varying from 4 to 30 mm. in thickness. Sometimes within the thicker bands there is a concentration of the crystals in minor



Text-fig. 5.—Calcite-muscovite mudstone; Hendre Mines, north-west slopes of Moelfre. General aspect showing the relationships of the twinned scalenohedra of calcite in section. Magnification 5½ diams.

layers parallel to the bedding. The crystals only very rarely appear within the compact "horny" layers.

Under the microscope the calcite-bearing bands are seen to consist of large porphyroblasts of mangancalcite set in a very fine-grained matrix consisting essentially of chlorite with subordinate colourless garnet, quartz, and a fair amount of relatively large crystals of colourless muscovite. The mangancalcite occurs in scalenohedra, up to 4 mm. and sometimes more in length, which have a characteristic triangular outline in section. Almost invariably these scalenohedra are twinned (Text-figs. 5 and 6), the twin plane being the $10\bar{1}1$. Quite often this twin plane is of the simple type[1] consisting of two half scalenohedra twinned on 1011. Frequently, however, each individual is represented by a complete crystal, the twin plane still being the $10\bar{1}1$, and the resulting twin appearing as a cruciform interpenetration form (Text-fig. 6) the angle between the vertical



Text-fig. 6.—Calcite-muscovite-chlorite mudstone; Hendre Mines, north-west slopes of Moelfre. A. Cruxiform interpenetration twins of mangan-calcite scalenohedra set in a fine-grained matrix of chlorite, quartz, muscovite, and magnetite; magnification 13 diams.; Nicols crossed. B. The muscovite has an ophitoblastic relationship to the calcite and a porphyroblastic relationship to the finer-grained chloritic matrix; magnification 40 diams.

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[1] See fig. 448, Dana's *Textbook of Mineralogy*, ed. by W. E. Ford, New York, 1932, p. 189.

axes of the twinned crystals varies in section up to nearly 90 degrees. In addition to these twin forms, twin laminae are often present. These can be separated into two forms: (*a*) parallel to the main twinning, i.e. to $10\bar{1}1$, and (*b*) twinning parallel to $0\bar{2}21$. The margins of the crystal are clearly defined though the apical coign may be broken away or frayed. The relief is high and the birefringence extreme. Extinction is parallel to the principal axis, i.e. a line bisecting the apical angle of the crystal. The interference figure is uniaxial and negative.

The crystals have no particular orientation within the rock and they tend to lie in all directions in sections cut both parallel and transverse to the bedding. Thus their orientation bears no relationship to any possible direction of stress. They contain numerous inclusions of fine-grained matrix material, and the banding of the mudstone is discernible under low powers of the microscope, the bands being carried across the crystals as variations in the amount of included matter. This expression of the original minor banding of the rock within the crystals themselves, shows that the crystals have had their origin *in situ*. The inclusions examined in detail are seen to consist of chlorite, minute colourless garnets, and (?) dialogite in globular granules. Also larger crystals, relatively infrequent, of muscovite occur. The latter may be totally included within the mangancalcite, or they may have a kind of ophitoblastic relationship, being partly enclosed by the crystal and partly within the matrix (see Text-fig. 6 B). Small rare magnetite crystals also occur as inclusions.

The chlorite of the matrix occurs as individual lath-shaped crystals sometimes with pseudo-hexagonal terminations. They vary in size up to 0·05 mm. and have a length to breadth ratio of 7 : 1 to 3 : 1. They are pale green and almost non-pleochroic, and are apparently identical with those occurring in the garnet-quartz rock. The colourless garnets are identical with those occurring in the other mudstone types.

The colourless mica occurs as tabular crystals with irregular and broken terminations. The smooth edges, forming the length of the crystal are parallel to the only cleavage, which is well developed (Text-fig. 6 B). In size they vary from 0·12 mm. × 0·045 mm. to 0·03 mm. × 0·012 mm.

The refractive index varies from slightly above to below that of the chlorite, and the birefringence is strong, the interference colours ranging up to second order reds and indicating a birefringence value of approximately 0·035–0·040. Extinction is parallel. The interference figure is biaxial and negative and its form indicates a fairly high axial angle and a weak dispersion. All these properties agree with those of muscovite. The amount present varies considerably in different bands, and the crystals are usually orientated in all directions.

Some of these bands develop large quantities of this muscovite and contain no crystals of mangancalcite. In some of these cases the muscovite crystals are relatively large. The paler green "horny" layers are essentially the same as the garnet-quartz rock, but the amount of garnet varies considerably. Several bands with relatively small garnet development exhibit shapeless fragments of a colourless mineral having a relatively high birefringence, and these suggest muscovite which is in the process of being broken down to form the massive garnet-quartz rock.

IV. DISCUSSION OF THE METAMORPHISM.

(*a*) *Production of the normal mudstone* (Analyses I and II, Table, p. 380).—It is postulated that the rocks when they were laid down consisted of quartz as minute detrital fragments, colloidal clayey and siliceous materials and manganese carbonate formed from solution. Secondly that the minerals which compose the rock at present have resulted from chemical reactions, chiefly among the alumino-siliceous colloidal materials of the original sediment. Owing to the marked uniformity in character of the type over such an extensive area, these mineral changes are regarded as having been induced by general regional metamorphism, which was the result of a uniform increase in pressure and temperature caused by the increasing weight of superposed materials as the rocks concerned sank beneath the Caledonian Geosyncline.

The metamorphism was essentially low grade, the essential character being recrystallization of the alumino-siliceous materials to form chlorite and sericite. The general metamorphism of these rocks, therefore, corresponds to the first or chlorite zone of normal regional metamorphism as described by Barrow (1893, 1912), Goldschmidt (1915, 1921), Tilley (1926), and others. The chlorite resulting from this first recrystallization is very uniform in character, there being practically no variation in colour or optical properties throughout the normal mudstones of the whole area. Owing to its fine-grained nature and intimate admixture with the other constituents it was impossible to separate the chlorite from the normal mudstones. However, chlorite having identical optical properties occurred as the only other constituent of note (except silica) in a thin band containing spherulitic carbonate. On treatment with warm dilute acid the carbonate readily dissolved leaving a residue composed essentially of the chlorite and silica. The analysis of this residue is given in I below. From this, if the very small amounts of sericite and magnetite present be neglected it is possible to calculate the approximate composition of the chlorite. This is done by calculating the ratios $RO : R_2O_3 : H_2O$ and neglecting the silica. This calculated composition for the chlorite is given by column II.

	I	II	III	IV	V	VI	VII	VIII
SiO_2 . .	56·89	21·50	24·8	24·7	24·97	25·72	23·3	23·52
Al_2O_3 . .	14·42	27·03	18·3	19·1 (+ TiO_2)	23·76	20·69	21·4	22·35
Fe_2O_3 . .	0·31	0·58	7·3	5·2	1·55	4·01	2·0	1·92
FeO . .	13·34	25·01	25·2		26·86	27·79	28·6	28·78
MnO . .	1·69	3·17	1·2	33·0	—	—	0·3	0·32
MgO . .	4·91	9·21	10·1	4·3	10·81	11·70	10·7	10·79
CaO . .	1·24	2·32	—	4·4	—	—	—	0·39
H_2O . .	5·96	11·18	12·9	9·3	10·71	10·05	10·5	11·28
$Na_2O.K_2O$	1·41	—	—	—	—	—	—	—
	100·17	100·00	99·8	100·0	98·66	99·96	96·8	99·35

I. Residue containing chlorite from carbonate rock, Barmouth.
II. Recalculated composition of the chlorite in I.
III. Chlorite from the Stavenger District (Goldschmidt, 1921, p. 59).
IV. Chlorite from the quartz-garnet-chlorite-phyllite, E. of Cleve Valley, Duchess County, New York (Barth, 1936, p. 795).
V. "Aphrosiderite," cited by Orcel (1927, p. 359); from Larsen, E. S., and Steiger, G., "Mineralogic Notes (Aphrosiderite, thuringite, and griffithite)," *Journ. Wash. Acad. Sci.*, vii (1917), p. 6.
VI. "Aphrosiderite," cited by Orcel (1927, p. 359); from Erlenmeyer, L., "Ueber ein dem Aphrosiderit F. Sandbergers ähnliches Mineral," *Zeits. f. Chem. und Pharm.* (1860), pp. 145–150.
VII. "Aphrosiderite," cited by Orcel (1927, p. 388); from Richard, G., "Veins with fibrous quartz and chlorite from the vicinity of Providence, Rhode Island," *Amer. Min.*, x (1925), pp. 429–433.
VIII. "Ripidolite," cited by Orcel (1927, p. 357); from Batesville, Virginia.

The present chlorite can be represented by the molecular composition: 3 Amesite, 3 Daphnite, 1 Ferro-antigorite, and according to the graphical representation given by Winchell (1933, p. 280) falls into the group of aphrosiderites and shows transitions to the ripidolites.

It will be noted that this chlorite is very rich in Al_2O_3 while Fe_2O_3 is almost negligible. There is, however, a considerable Fe_2O_3 content in the rock (see anals. I and II, p. 380), a factor which is represented mineralogically by magnetite. The crystallization of magnetite occurs at this early stage (Harker, 1932, p. 210) as also does that of any pyrite that may be present.

The garnet associated with these rocks is of special interest. Normally garnet is the result of metamorphism of rather a high grade and follows the appearance of biotite in the normal sequence of mineral production (Barrow, Tilley, Goldschmidt). In the present case quite abundant minute garnets are noted in the normal chlorite-bearing mudstone, with no associated biotite whatsoever, and it seems that in this case the garnet must be regarded as part of the chlorite zone itself. Many instances are now recorded of garnet occurring in the chlorite-bearing rocks prior to the formation of biotite. In every case, however, the garnet occurring was of a particular type and notable for a large manganese content. Goldschmidt (1921, pp. 60 ff.) records quartz-muscovite-chlorite-garnet phyllite succeeding quartz-muscovite-chlorite phyllite in the Stavanger district, the garnet containing 12·28 per cent of MnO. Tilley (1923, p. 198) notes garnet immediately after the lowest grade (of quartz-muscovite-chlorite-albite rocks) in the Start area, and this contains 5·5 per cent MnO. Phillips (1928, p. 550) records minute spessartite garnets (12·5 per cent MnO) in the chlorite phyllites of North Cornwall. Williams (1927, p. 361) describes spessartite in a grit band among the Talgau Lavas of Snowdon associated with chlorite and green biotite. Garnets containing 0·35–1·23 per cent MnO are recorded by Barth (1936, p. 785) from the low grade quartz-garnet-chlorite schists of Duchess County, New York. Tilley (1928, p. 50) also notes that the presence of manganese promotes the formation of garnets in contact zones of pelites. The colourless garnets in the present case were too small to isolate but optically they are almost identical with the minute garnets of the manganese ore in the same group of rocks. These latter contained 36–39 per cent of MnO, corresponding to 85–90 per cent of the spessartite molecule. It is thus indicated that the garnets of these mudstones also contain a very high percentage of manganese. The two analyses of the normal chlorite-sericite mudstone bearing gave 12·23 and 13·59 per cent of MnO respectively. Only a relatively small proportion of this, however, enters into the composition of the garnet, the bulk remaining in the form of dialogite. Thus once more the theory that manganese present in significant quantities leads to the much earlier development of garnet than would otherwise be the case is borne out. The garnet would be formed by the interaction of chlorite and sericite with manganese carbonate and silica :—

$$\underset{\text{(chlorite)}}{2Al_2O_3.(Mg, Fe)O.3SiO_2.5H_2O} + \underset{\text{(sericite)}}{K_2O.(Mn, Fe)O.2Al_2O_3.7SiO_2.2H_2O}$$

$$+ 2SiO_2 + \underset{\text{(dialogite)}}{10MnCO_3} =$$

$$\underset{\text{(garnet)}}{4\,[3(Mn, Fe, Mg)O.Al_2O_3.3SiO_2]} + 7H_2O + K_2O + 10CO_2.$$

With regard to the formation of tourmaline in these mudstones the folowing comparisons are noteworthy: The lower grits of the Arenig (Plas-y-Nant) Beds of Snowdon are extensively tourmalinized. Williams (1927, pp. 334–5) states that the cause of their tourmalinization is unknown and that "there is no certain record of tourmaline in the Mynydd Mawr 'riebeckiete-granite' a mile and a half distant, so that the tourmalinization may be unconnected with that intrusion". Concerning similar rocks at the same horizon near Llanberis, Fearnsides (1908, p. 704) remarks: "There has been much thrust-faulting along the unconformity, but no large intrusive mass of igneous rock has been observed within five miles of the locality." In Duchess County, New York, tourmaline occurs scattered over the whole area in all kinds of rocks, far away from any granitic intrusions (Barth, 1936, p. 792). Harker (1932, p. 119) states that " tourmalinization may indeed be found at a considerable distance from a granite contact, but only in proximity to tourmaline-quartz veins which mark the channels of supply ". The consensus of opinion regarding authigenous tourmaline in sediments is that it is always of pneumatolytic origin even though it occurs far away from the nearest possible source of supply. While this view is favoured in the present case it does not seem impossible that these small amounts of tourmaline may be the result of recrystallization of materials resulting from the degradation of allothigenous tourmaline. The grits contain abundant detrital tourmaline, and this must be represented in some form in the mudstones. However, rare greenish blue tourmaline is recorded in occasional quartz veins that traverse these rocks, and these quartz veins may have been the ultimate source of the tourmalinizing solutions.

(*b*) *The more advanced metamorphism of the Hendre locality.*—The biotite-bearing mudstone (p. 369) indicates the commencement of the " biotite zone " of normal regional metamorphism. The characters of the residual chlorite are the same as in the normal mudstones, and this undergoes no further recrystallization with the advent of biotite. It thus seems that the formation of biotite is only a slight metamorphic advance on the normal chlorite-sericite stage. Phillips (1930, p. 250) states that " one of the earliest changes in the chlorite zone is the production of green-brown biotite ". It is noteworthy that the biotite formed in the present case is a distinctly green-brown variety, and it appears that such a form is characteristic of the first stages of the development of biotite. Tilley (1925, p. 103) states : " It is of consequence to note here that the common brown biotite is now in question. A green to brownish-green pleochroic biotite arises at an early state of metamorphism." Unfortunately owing to the insuperable difficulty of separating the mineral, no information is forthcoming regarding the exact composition of the biotite.

Comparing analyses III and IV with I and II it is noted that the biotite rocks have approximately the same bulk composition as the normal mudstones. The changes resulting in the formation of biotite, therefore, can be assumed to be merely mineralogical transformations and not the result of introduction of any material from outside. The biotite appears to result from the interaction of chlorite with sericite.

A further progressive stage in this metamophism is represented by the garnet-quartz rock (p. 370). The bulk analysis (V) of this rock is approximately the same as those of the two preceding types, and one is again justified in considering that it resulted from mere mineral transformation. In this case, as is usual, the large scale development of garnet clearly represents a stage beyond the formation of biotite. Since the garnet makes up most of the rock, and quartz most of the remainder, the analysis V exclusive of the figure for quartz gives a good idea of the composition of this garnet. Although still rich in MnO, it probably contains much more FeO and CaO than the colourless garnets of the normal mudstones. Goldschmidt (1921, p. 69) noted that when garnets were formed accompanying both low grade and high grade metamorphism the high grade garnets show a decreasing content of MnO, with a corresponding increase of FeO, the garnets tending to approach the normal almandite type.

The very small size of the garnets is probably due to the relative ease of formation when manganese is present. Many centres of crystallization would readily be initiated and the garnet material would thereby be used up before the individuals reached any marked size. The occurrence of very small garnets which contain very notable manganese percentages is recorded by Coulson (1911–1914, p. 289), Williams (1927, p. 360–1, fig. 2*b*), Fermor (1909, plate 11, fig. 1), Phillips (1928, p. 550), and Renard (1878, p. 22).

The chlorite accompanying these garnets is very pale and indicates a magnesian-rich penninite. This indicates that on the formation of garnets from chloritic materials, iron is taken up by the garnets far more readily than is magnesium, and that while with increasing metamorphism garnets are enriched in iron, any residual chlorite is enriched in magnesium. Tilley (1926, p. 44) states: "In these cases (garnet-chlorite associations) the chlorites are all much richer in magnesia than the garnets. Actual exchange of magnesia for ferrous oxide, alumina being unchanged, is suggested."

	A	B
SiO_2 . .	16·31	—
Al_2O_3 . .	2·56	—
Fe_2O_3 . .	1·77	1·97
MnO . .	3·34	4·15
CaO . .	41·10	51·00
CO_2 . .	34·54	42·88
	99·62	100·00

The three rock types above considered represent three stages of metamorphism of the same original rock type. They have a similar bulk composition and so form an isochemical series. The fourth type—the calcite-muscovite rock, presents a rather different problem. Consideration of the chemical analyses (VI and VII, p. 380) show that there are marked discrepancies when compared with those of the preceding types, and consequently they cannot be regarded as isochemical with the latter. The chief points of difference are: Lower SiO_2 content; higher Al_2O_3; much lower MnO; somewhat higher MgO; and much higher CaO. Mineralogically the rock differs from the normal type in possessing scalenohedral crystals of calcite and well developed muscovite. The calcite was isolated by hand picking from roughly crushed material and the analysis of the separated mineral is shown on p. 379. A is the analysis of the complete separated portion and B the computed analysis of the calcite.

If from the analyses VI and VII the compositions of the matrices of these rocks be calculated by subtracting the calcite as indicated by the CO_2 content, it is still found that these bear no closer relationship to the ordinary mudstone than before. Therefore the calcite-muscovite bearing rocks must be regarded as separate metamorphic derivatives of the normal mudstones. It is not easy to see how the increase in calcium came about. There is no evidence whatsoever that it has been brought about by bodily introduction from extraneous sources, and no basic (or acid) intrusion is recorded anywhere in the immediate vicinity. Veining is not common and the calcite rocks themselves are practically unaffected by veining.

TABLE OF CHEMICAL ANALYSES

	I	II	III	IV	V	VI	VII
SiO_2 .	40·96	42·57	41·81	46·90	54·89	32·13	40·71
Al_2O_3 .	12·84	13·08	12·28	14·86	15·70	22·97	19·90
Fe_2O_3 .	3·23	4·89	2·72	2·23	0·49	13·59 (chiefly FeO)	1·99
FeO .	6·49	5·30	6·18	7·09	6·12		11·34
MnO .	13·59	12·23	12·89	8·57	12·44	2·25	5·05
MgO .	2·44	1·81	1·92	2·00	1·74	6·50	2·91
CaO .	2·67	2·72	4·48	3·35	6·69	11·04	7·26
Na_2O .	1·14	1·57	1·76	2·01	n.d.	1·75	0·97
K_2O .	3·60	3·92	4·57	4·46	n.d.	—	3·65
P_2O_5 .	0·23	0·20	0·26	0·25	0·18	n.d.	0·14
H_2O- .	0·05	0·06	0·05	0·06	0·06	0·05	0·04
H_2O+ .	2·43	1·84	3·08	2·95	0·12	ignition	3·88
CO_2 .	10·14	9·37	7·74	4·87	1·07	10·59	2·41
S .	0·10	0·16	0·18	0·14	0·07	n.d.	0·08
	99·91	99·72	99·92	99·74	99·57	100·87	100·33

I. Quartz-chlorite-sericite-spessartite-dialogite mudstone, St. John's Church, Barmouth.
II. Do. Egryn Mines, 3½ miles N. of Barmouth.
III. Quartz-chlorite-biotite-spessartite-dialogite mudstone, Hendre Mines, N. of Moelfre.
IV. Do. Do.
V. Quartz-garnet rock, Hendre Mines, N. of Moelfre.
VI. Calcite-muscovite-chlorite mudstone, Hendre Mines, N. of Moelfre.
VII. Do. Do.

(Analyses by A. W. Woodland.)

What veins do occur are normal quartz veins with little or no calcite. On the other hand, the fact that the scalenohedra are aligned along bedding planes seems to indicate that the difference in composition was original. Local concentration of calcium instead of manganese would explain the differences largely, though it is not easy to see why such a difference should occur in such a small area surrounded by sediments which are remarkably constant in composition. The large scale recrystallization of muscovite in these rocks suggests that the aluminous materials were largely of sericitic composition. The fact that the chlorite is pale green and only feebly pleochroic suggests that it is a magnesian-rich variety, and that the muscovite is a type rich in ferrous iron. These rocks pass into the garnet-quartz rock, and this indicates that their grade is approximately equivalent to the biotite grade in the same locality. During the crystallization of the muscovite there was probably transference of FeO from the chlorite to the mica, so leaving a chlorite relatively rich in MgO.

The reason for the localization of these peculiar metamorphic types in this small area is to be found in the local tectonics. This small area lies in the apex of a pitching monoclinal syncline on the north-west slopes of Moelfre. The pitch is west and the south limb dips approximately north. The apex of this fold would be a region of increased pressure, which would be responsible for the mineralogical changes demonstrated. Apart from mineralogical changes the local increase in pressure is clearly shown by the minor crumpling exhibited especially by the garnet-quartz rock.

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REVIEW.

THE GEOLOGY OF THE OILFIELD BELT OF IRAN AND IRAQ. By G. M. LEES (*Science of Petroleum*, pp. 140–8).

GEOLOGISTS are indebted to Dr. Lees for summarizing the geology of the Zagros Mountains and their foothills in the space of eight pages. This paper, together with the recent papers by D. N. Wadia, throws a flood of light on the structure of a large part of Asia. The area reviewed is 1,200 miles long and up to 500 miles broad, and this strip is not left in the air, but is connected for us to the Dinaric limb of the Alpine Mountain System. At the south-eastern end the thorny problem of the syntaxis of the Zagros and Oman is outlined but not solved, and indeed until the Bandar Abbas alluvium be removed and the Persian Gulf dried up, no satisfactory solution can be expected. The Persian mountains form an ideal example of a fold system with movement directed from north-east to south-west, with overthrusts in the north-east and gentler folds in the south-west where an alluvial-filled synclinorium of the Iraq plains occurs. To the Upper Cretaceous and Miocene-Late Pliocene orogenic movements cited by the author the reviewer would wish to add one of Jurassic or early Cretaceous age.

Crystalline schists and gneisses in the north-east are of unknown age and are not necessarily pre-Cambrian. Lower Cambrian red sandstones, shales, gypsum, and salt underlie Upper Cambrian comprising fossiliferous shales and micaceous sandstones with limestone reefs. Ordovician and Silurian fucoid beds, quartzites and graptolite shales are known only in the south near Bandar Abbas. Near here 400 feet of quartzite is assigned to the Devonian, but Upper Devonian fossils have been found below it, so that it must probably now be relegated to the Carboniferous. Elsewhere there is a gap between Upper Cambrian and Upper Carboniferous. Marine Upper Carboniferous occurs in the south, but in the north plant-bearing sandstones of this age have been found resting without angular unconformity on the Upper Cambrian. Thick limestones with fusulinids and corals represent the Permian, and Lower Triassic limestones, dolomites, and shales with sparse "Werfener Schiefer" fauna succeed it. Middle Triassic (Carnic) has been identified in one region, and Upper Triassic with *Orbitopsella* elsewhere. The Jurassic occurs in three facies, radiolarian chert, ammonite-bearing bituminous limy shales, and massive limestone with the problematical fossil *Lithiotis*. Lower and Middle Cretaceous up to Cenomanian are predominantly massive limestone and Senonian and Maestrichtian mainly marlstone, although locally the upper part thickens and is sandy where reefs occur carrying *Loftusia* and numerous rudists.

Eocene deposits vary and are present as marls, nummulitic limestone, sandstones, and, in the south, gypsum beds and red marl. In Oligocene and Lower Miocene thick anhydrite deposition and reef or normal limestone form a complex, except in the south-west where in a short distance the limestone changes to shale mixed with thin anhydrite beds. The Asmari Limestone or main oil reservoir rock in Persia is of this age. The Miocene and Pliocene are strongly developed. The Lower Fars is a widespread deposit of anhydrite, marl, salt, and thin limestones which are numerous in the north and sometimes rare in the south, where three stages are recognized. Stage I (basal) consists of grey marl, anhydrite and much salt with thin oil-shale and locally limestones. Its thickness is exceedingly variable, partly on account of the disharmonic folding which has occurred. Stage II consists of red and grey marls, anhydrite and some salt and is more regular. Stage III consists of anhydrite and grey marls. The Middle Fars is not distinguished in the north. In the central part it reaches a thickness of 2,500 feet made up of green marls and fossiliferous marly limestones. The Upper Fars is composed of variegated marls interbedded with brown sandstone and in part is of marine origin. Bakhtiari conglomerates of Pliocene age overlie it unconformably.

Oil indications occur as veins and pockets of bitumen, manjak, and impsonite, in Eocene, Cretaceous, and Jurassic rocks and as seepages from Cretaceous and higher horizons. All the oilfields developed to date, except two, had active escapes of oil and gas above them and the other two had gas escapes. These lead to the formation of Gach-i-Turush (sour gypsum) which is encountered in borings to a depth of not more than 200 feet below the surface.

A figure of three sections shows the disharmony existing between the surface formations and the more rigid limestone masses in the oilfields area, near Masjid-i-Sulaiman, Haft Kel, and Gach-i-Garaghuli, and of part of this area a more detailed map is given and discussed in the text. The fact that the sections are taken down to 25,000 feet below the surface means that in a large part the hidden folds are conjectural, as is stated on the figure, and their shape expresses a convention which does not meet with absolute concurrence of opinion on all sides, but as the truth is not known may represent a reasonable compromise. In the final section the nature of the oil reservoir conditions is set down and the importance of fissures in the matter of feeding the wells pointed out. It may be added that a short review of the salt-plugs is given and of the controversy which the theory of their origin has produced. It is not unconnected with the age of the salt in the Salt-Range of India.

J. V. H.

CORRESPONDENCE.

ELSWORTH ROCK AND OTHER MATTERS.

Sir,—Since by an oversight this correspondence was closed without my being given the opportunity to reply to Dr. Spath's third letter, I trust that in fairness you will allow me to make the following brief rejoinder.

1. *Am. cordatus.* When an authoress (not a reviser) uses words which, without her realizing their repercussions or even using them correctly, necessitate changes in the stratigraphical as well as palæontological usage of a century, it is not a " deplorable attitude " to submit a formal application for suspension of the rules, as Dr. Spath knows I have done.

2. *Am. serratus.* This is entirely irrelevant to the discussion, but since Dr. Spath has dragged it in I repeat that it was he, not I, who " gratuitously altered " the conclusions of the reviser, Salfeld.

3. The total quantity of foreign material at the British Museum has nothing to do with the amount of Corallian material from Europe, which, further, must be judged in relation to the quantity in Continental museums before its adequacy can be asserted.

4. Readers familiar with Dr. Spath's writings prior to July, 1938, will be as amused as I am at his reference to S. S. Buckman as " that genius " in connexion with his pulverization of stratal units. I could give half a page of citations which would provide a surprising contrast !

5. An allusion to missing foreign faunas would cease to be mysterious if particulars were given. In default of particulars it cannot be said to be mysterious only to me.

W. J. Arkell.

Oxford.
16th July, 1938.

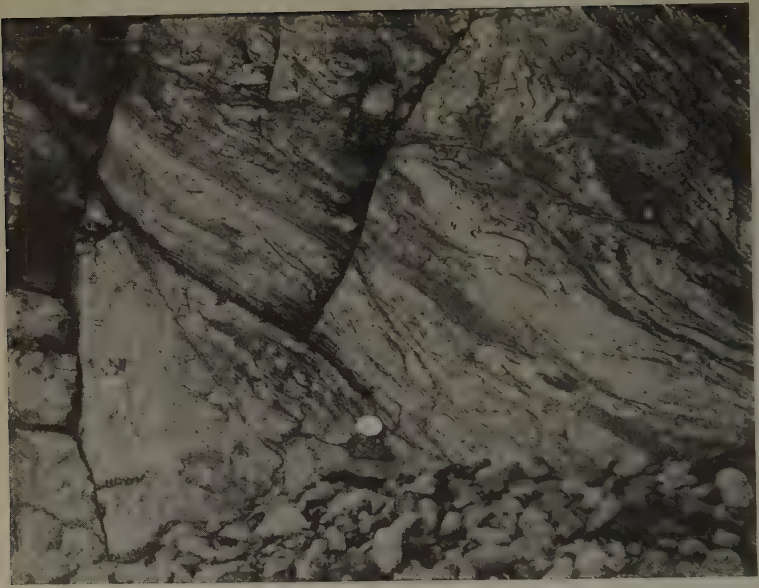

FIG. 1.—Finely banded and contorted Kennack Gneiss in Pen Voose Cove. The diameter of the watch-face is 2 inches.

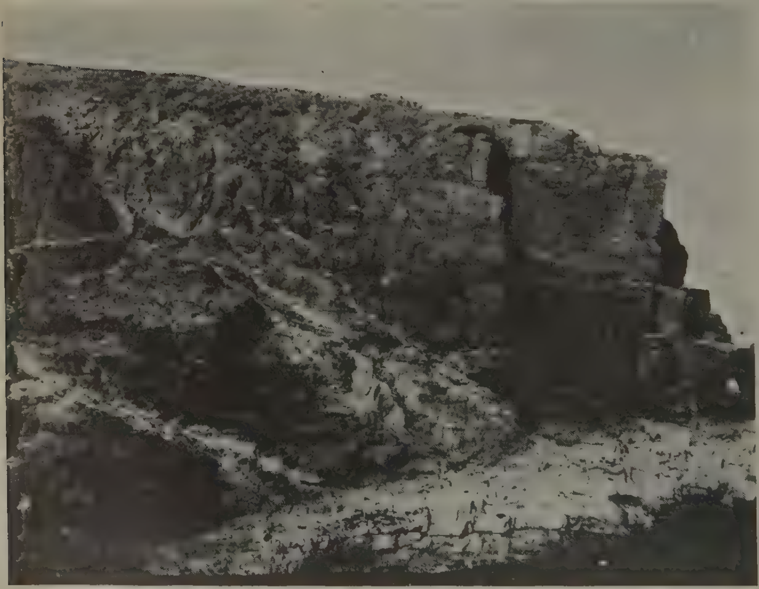

FIG. 2.—Hornblende-schists in Church Cove, showing the gentle easterly foliation-dip and acid Kennack veins cutting the schists.

Photos J. B. S.

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ORIGINAL ARTICLES.

Notes on the Geology of the Lizard Peninsula.

No. 2. The Primary Hornblende-schists and Gneisses (The Lizard Hornblende-schists).

By J. B. Scrivenor.

(PLATE XV.)

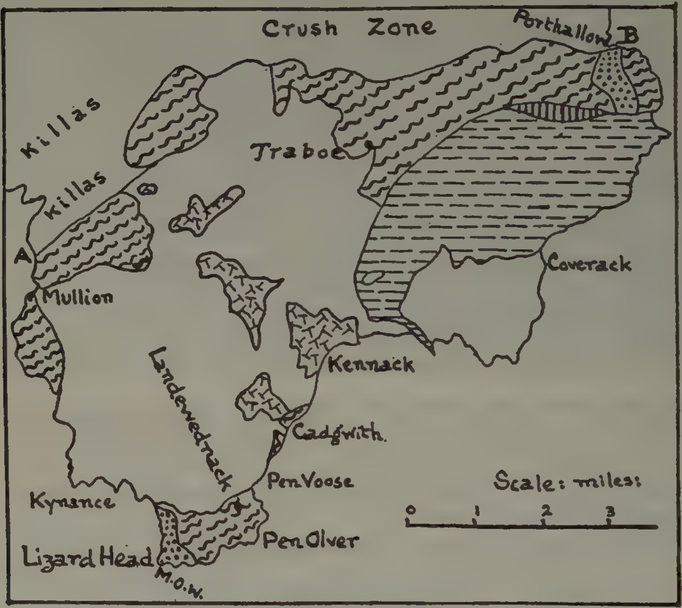
BEFORE proceeding further with these notes on the geology of The Lizard it will make matters clearer if the sequence of rocks is given as established by the Cornish and other geologists, but I have ventured to introduce modifications which will be explained later :—

Youngest : Kennack granite.
Kennack gneisses, consisting of doleritic and granitic components.
Dolerite dykes and their derivatives.
Gabbro.
Serpentine.
Hornblende-porphyrite dykes and veins of quartz-diorite-pegmatite.
Primary hornblende-schists and gneisses.
Man of War gneisses.
Oldest : Old Lizard Head Series (mica-schists, " green schists," and altered quartzite) and the Treleague quartzite.

In the present paper the rocks described in the 1912 Memoir as the Landewednack hornblende-schists and the Traboe hornblende-schists will be discussed as primary hornblende-schists and gneisses ; and the relationships to other rocks of hornblende-porphyrite dykes (the Polpeor dykes of the Memoir, p. 113) and of quartz-diorite-pegmatite veins at Pedn Tiere, near Porthallow, will also be considered.

The distribution of the rocks described in Chapter IV of the Memoir as " The Lizard Hornblende Schists " is shown roughly in Text-fig. 1.

The Landewednack hornblende-schists are described as highly metamorphosed crystalline lavas or dolerite sills: "to go further than that is impossible; they are so highly metamorphic that their original stratigraphical relationships cannot be made out" (p. 49). The Traboe schists on the other hand are described as "an intrusive facies of igneous activity which preceded the injection of the serpentine. Their relations to the epidotic hornblende-schists [the Landewednack type, but a large part of the Landewednack schists cannot be described correctly as epidotic. J.B.S.] are difficult to make out. Sporadic occurrences of rocks of this type appear among the epidotic schists, at Pedn Tiere (Porthkerris Point, to the east of Porthallow), Halwyn (west of Porthallow), and in many other places. They are folded with the epidotic schists till their original relationships are no longer decipherable, but there is nothing to forbid the supposition that they are intrusive gabbros and dolerites which invade the other



Text-fig. 1.—Map showing the main outcrops south of The Lizard Boundary which is the sinuous line from A, near Mullion, to B, at Porthallow. Kennack Granite ⁂. Kennack Gneisses at Kennack, Cadgwith and Pen Voose, not shown separately. Gabbro ═══. Serpentine, white. Hornblende schists and gneisses 〰〰. Man of War Gneisses, M.O.W., off Lizard Head. Treleague Quartzite ||||||. Mica Schists and associated rocks ⁘⁘. The outcrops as shown are approximately the same as those on the Geological Survey 1 in. map (1932), from which they have been copied.

group. . . . They are always folded with the marginal serpentine and show transitions to it" (pp. 51, 52).

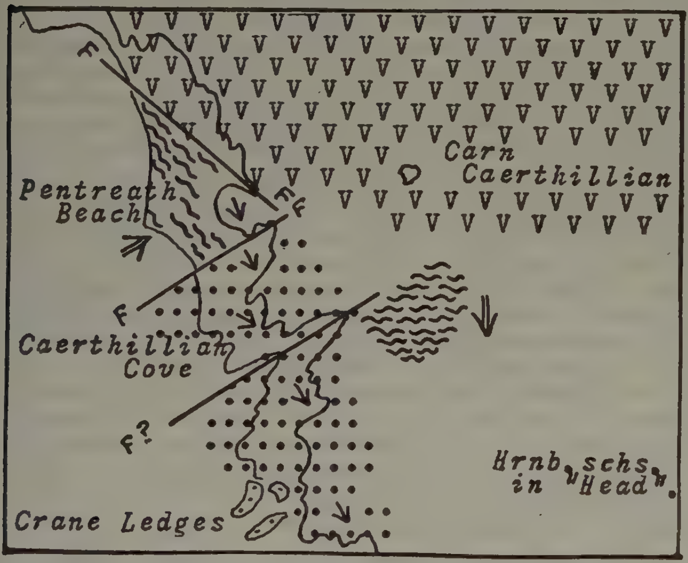
The position of Traboe, where the type-specimens of these schists were collected, is marked in Fig. 1, in the schist area close to the serpentine, but I am told that the type-specimens came from large isolated boulders of stone that have since been completely broken up for road-metal. When I visited the locality I could not find anything that could certainly be separated from the Landewednack type, and to put the matter briefly, the result of field-work and examination of the slides in the Sedgwick Museum and Geological Survey collections, together with my own slides, is that I cannot follow the division of these schists into Landewednack and Traboe types; but close to the serpentine, where there is very good evidence that the latter rock was intruded into the schists while the latter were still hot and plastic, resulting in curved and sometimes intricately sinuous junctions, brown hornblende, which may be the result of contact metamorphism, is of fairly frequent occurrence, in marked contrast with the characteristic deep green hornblende of these rocks; while it appears to me that if, as is argued in the Memoir, it is permissible to regard the Traboe type as an intrusive rock, the same is equally permissible in the case of the Landewednack type, excepting the highly epidotic rocks of Pen Olver, Polledan Cove, Hot Point, and Cadgwith, the origin of which will be discussed in a later contribution. With these exceptions all The Lizard Hornblende-Schists can be simply explained as primary banded and foliated schists and gneisses, according to the variation in grain, that solidified as they are now from an intrusive magma; and it does not seem to be necessary to assume that they are in any degree metamorphic, except perhaps at the junction with the serpentine, in the sense that they are the result of the metamorphism of pre-existing rock or rocks, of which there is no evidence in the field, and for which there is only very slight support in the slides I have examined. It is of course not denied that such rocks can be and have been formed from basic lavas and basic intrusive rocks elsewhere, but a transition from the original to the metamorphosed rock can be traced and is logically required as proof of the metamorphism. I have been told that the Landewednack type of hornblende-schists represents basic lavas and minor intrusions that have been completely reconstituted and the chemical composition is cited in support of that statement; but it may be argued that any igneous magma results from the complete reconstitution of something else after fusion, and in this case the chief objection is that there is no field-evidence of these rocks having been formed by the metamorphism of pre-existing rocks.

The hornblende-schists described as of Landewednack type are best seen in the southern part of the Lizard Peninsula, where the pretty little village of Landewednack with its old church nestles among trees in a valley that ends in Church Cove. Along the coast from Church Cove to Pen Olver, Housel Bay, and Polbream Cove, there are magnificent cliff-sections of these rocks. At Pen Olver, Polledan Cove, and Bass Point are inclusions of the Old Lizard Head Series and a wonderful development of epidote. At Cadgwith are smaller areas of these hornblende-schists.

In Polbream Cove (for the position of this and other localities not shown in Text-fig. 1 see Ordnance Survey 6 in. sheet lxxxiv S.E. and xc N.E.) the junction between the hornblende-schists and the Old Lizard Head Series is faulted. There are at least two faults; one, which can be traced through two rocky promontories on the beach where caves have been formed along it, trends E.N.E.–W.S.W. and hades very steeply to the N.N.W. The other fault trends about N.N.W.–S.S.E. and is vertical. Where these two faults intersect the rocks have been so shattered that the original relation of the hornblende-schists to the Old Lizard Head Series cannot be determined nor can the amount of throw be measured; but when one looks at the cove from the sea it is evident that the hornblende-schists, with gentle dip to the east, could be produced westward over the Old Lizard Head Series without postulating any throw at all. All one can say about this junction is that two intersecting faults have shattered it badly. North of Church Cove, at The Balk, the junction is again a dislocation. In the Memoir (pp. 45 and 46) it is described as the eastern end of a great thrust, the western end being on Pentreath Beach, by which the serpentine has been driven southwards over the schists, but it may be a normal fault with the serpentine on the downthrow side. It hades to the N.W. and close to it the schists have a similar foliation-dip, but only a short distance away, on the north side of Church Cove, the foliation-dip of the schists is gentle to the east, and this dip continues, but for local contortions, as far as Bass Point. In Polledan Cove and on Pen Olver the general foliation-dip is N.W.: between Pen Olver and Housel Cove it is northerly. In Housel Cove there is a fault along a vein of acid rock hading 45° N.E. On the N.E. side of this fault the foliation-dip is N. On the S.W. side it is N.W. and continues N.W. to “ Bolijack ”. Then from Bumble Rock to Polbream Cove the foliation-dip is gentle to the E. These foliation-dips are mentioned because on the 1 in. Geological Survey map two of the three foliation-dips shown are misleading.

On the west coast these schists are shown on the 1 in. map and on the 6 in. sheet in the Geological Survey Library as reaching the sea as an outcrop extending from Caerthillian Cove to the south end of Pentreath Beach. My mapping differs somewhat from this and is shown in Text-fig. 2.

South of Caerthillian Cove the rugged cliffs are composed of Old Lizard Head Series rocks with a S.S.E. to S.E. dip, which continues to Old Lizard Head and beyond. Scrambling along the rocks N.W. of Caerthillian Cove, where there appears to be a fault trending N.E.–S.W., one finds that the Old Lizard Head Series rocks continue, there being one particularly fine 7 ft. bed of quartzite dipping S.E. with felspar crystals coating a joint-face, and with mica-schists below it. A little farther on is a good exposure of "green schists" and mica-schists with a porphyritic intrusive rock forming a sill 4 inches thick. Continuing north, one comes to an unnamed cove south of the steps that lead down to Pentreath Beach. Here is a well-marked fault trending N.E.–S.W. and hading 45° N.W. On the S.E. side of this fault are Old Lizard Head rocks with lenticles of igneous rock, but on the N.W. side the Old Lizard Head rocks appear to be mixed up with coarse hornblende-schist. The former are also seen in isolated masses of rock on Pentreath Beach. At the lowest spring tides reefs are exposed on Pentreath Beach composed of coarse hornblende-schists with a good deal of white felspar. These end against the dislocation that bounds the serpentine on this beach and is described in the Memoir as a thrust (p. 46). These reefs of coarse hornblende-schist on Pentreath Beach show a distinct foliation-dip to the E.N.E., but the Old Lizard Head Series rocks and the hornblende-schists in the promontory between the two faults shown on the sketch-map dip to the S.S.E.



Text-fig. 2.—Sketch-map of the coast west of Lizard Town. Scale, 6 in. to 1 mile. Old Lizard Head Series .... Hornblende schists, wavy lines in direction of foliation-strike. Serpentine, V V V V.

Owing to the proximity of the serpentine the Old Lizard Head rocks are very hard here and there appears to have been much shearing, so that their relationship to the coarse hornblende-schist is not as clear as it might be; but I think that the simplest explanation, and one which fits the Traboe type of schist described in the Memoir, is that here the hornblende-plagioclase magma was injected *lit par lit* into the Old Lizard Head Series.

In the Landewednack and Cadgwith areas the grain of the hornblende-schists varies considerably. Near the head of Caerthillian Cove I collected a specimen showing abundant phenocrysts of hornblende up to 2 mm. in length. At Cadgwith, where in the north cliff of the cove, between tide-marks, I found two well-marked bands of porphyritic schist, some of the felspar phenocrysts reach 3·5 mm. and a slide shows in addition diopside phenocrysts, one over 3 mm. long; but no phenocrysts in these schists are bounded by good crystal faces. On the other hand I collected at Cadgwith a very finely banded schist in which 20 bands were measured in a quarter of an inch. In Housel Cove the schists are almost as coarse as those around Mullion, where the grains sometimes exceed 1·5 mm.; but generally the grains of the schists in the Landewednack and Cadgwith areas are less than 1·5 mm. A remarkable contrast can be seen in the Mullion Cove quarry, by the road under the hotel, where bands of gneiss 5 inches thick are accompanied by schists as finely banded as that just described from Cadgwith. A slide from a thick, felspathic band shows that the felspar is completely decomposed and that the hornblende grains only average 0·33 mm. in length, therefore thick bands do not necessarily contain large grains. I could not see any reason to think that the rocks in this Mullion Cove quarry are two distinct series folded up together inextricably. Unless the slide just mentioned is exceptional there is not much difference in size of grain, and pressure during consolidation could account for the varying thickness of the bands.

Porphyritic hornblende-schists are by no means uncommon in The Lizard and have been mentioned by several authors.

As the petrology of these rocks has been fully described in the Memoir no detailed account is necessary here. The two chief constituents are green hornblende and a plagioclase felspar that is generally andesine but sometimes nearer albite. Labradorite or acid bytownite has been identified by Sir John Flett in five examples of Traboe type (Memoir, p. 51). Orthoclase is very rare.

Diopside is a common constituent but not always present. I have not seen any augite such as one finds in dolerites. Granular epidote is a common but not constant constituent and is sometimes very abundant.

Quartz is very rare. The late Professor T. G. Bonney mentioned a little as being present in a schist from Hot Point and said that some also occurred in the Cadgwith schists (*Quart. Journ. Geol. Soc.*, 1883, pp. 15 and 17), but the only rock of this group in which I have been able to prove quartz optically (apart from quartz-veins in the cliffs and quarries between Porthoustock and Porthkerris

Point) is a rock from an old quarry at Mill Mehal near St. Keverne (see 1 in. map, about one mile N.W. of St. Keverne). The rock is dark coloured, dense, and of medium grain. It shows slight schistosity. It consists of hornblende in ragged crystals, plagioclase with refractive index about the same as balsam, sphene, apatite, an opaque iron-oxide, and a little quartz forming patches of clear mosaic. This rock might be described as a melanocratic quartz-diorite ; and the presence of garnet in Treleague quartzite *in situ* close by suggests that the quartzite has been metamorphosed by contact with this quartz-diorite magma.

Sphene is of common occurrence and suggests by its habit the sphene of plutonic rocks rather than the sphene derived from ilmenite in "epidiorites". Sometimes it occurs as good crystals reaching 0·6 mm. in folia of felspar.

Apatite occurs sparingly and there is an abundance of black opaque mineral which is probably iron oxide, but the analysis on p. 48 of the Memoir, with 1·90 per cent of TiO_2 shows that ilmenite may be present also.

In one of my slides of porphyritic schist from Cadgwith I found a very little fine-flaked biotite, but I have not seen any in other slides cut from these rocks.

The abundance of hornblende makes most of these rocks melanocratic, which will explain the low silica percentages in the analyses by Radley (Memoir, p. 48), Hudleston (*Quart. Journ. Geol. Soc.*, 1877, p. 928), and J. H. Collins (*op. cit.*, 1884, p. 468). It must be added that Collins gave an analysis of a felspar band from schist collected at Porthallow with silica 43·16 per cent only, but the specimen was obviously impure and when recalculated for silica, alumina, lime, and "alkalies and loss" only, the analysis gives percentages for silica and lime that will not fit any felspar except anorthite, so it is probable that some of the lime was present as an impurity also.

With regard to the melanocratic nature of these rocks, Bonney described a specimen from the north side of Porthoustock Cove (*Quart. Journ. Geol. Soc.*, 1896, pp. 19 and 20) which was practically pure dark green hornblende, or hornblendite. On the other hand at Porthkerris Point and nearer Porthallow one may obtain beautiful specimens of black and white banded rock, the white bands being of felspar, the dark chiefly of hornblende.

If these rocks are the result of metamorphism of pre-existing basic lavas and sills, we may reasonably expect to see in sections traces of the original pyroxene from which the hornblende has been derived by uralitization and also traces of original ophitic structure. With regard to the latter, I have seen nothing convincing. With regard to the former, I have not, as already stated, seen any augite such as one expects in basic lavas and sills, but in a few slides I have seen diopside and hornblende associated in such a manner that it might be argued that the hornblende is uralitized diopside. Examples occur at Mullion, but the best I have seen is a schist from Carnbarrow, south of Cadgwith, in which there is a little diopside almost colourless in section, surrounded by hornblende in such a manner as to suggest that the latter is derived from the pyroxene (Sedgwick Museum Collection 13663). But of course uralitization of pyroxene can take place in a plutonic rock and the small amount of evidence for uralitization of diopside in these hornblende-schists is very slight support for their derivation from basic lavas and sills. Moreover, if so extensive an assemblage of lavas and sills once existed, it is very strange that there were no beds of ash also with terrigenous material, which would betray itself by schists of a different nature, with micas.

It may be objected, however, that in some of these rocks the foliation or banding is so fine, as in the Cadgwith specimen, that it is inconceivable that it originated from flow during the cooling and consolidation of an igneous magma. That primary gneisses are thus formed cannot be gainsaid : I have seen beautiful examples in Malaya among the granitic rocks ; but in this case we need not look very far to see what is possible in the production of finely banded gneiss by flow in a magma or mixture of magmas. Close to Church Cove is Pen Voose Cove (see Text-fig. 1), a locality famous for showing in its cliffs a marvellous mixture of Lizard rocks. In the centre of this cove is a large outcrop of banded Kennack gneiss. The photograph (Pl. XV, Fig. 1) shows how very finely banded and also how contorted a part of this gneiss is, and I think it is correct to say that now no one doubts that the Kennack gneisses were formed by the mingling of two magmas, a basic and an acid magma, during intrusion and consolidation. I have not seen any Kennack gneiss as finely banded as the Cadgwith specimen, but that is an extreme case. Anyone who accepts the Kennack gneiss banding as being due to flow of molten material should experience no difficulty in accepting the same explanation in the case of the primary hornblende-schists and gneisses with their bands and folia of different minerals.

THE HORNBLENDE-PORPHYRITE DYKES.

These are described in the Memoir (p. 113) as the Polpeor dykes and are stated to occur in the brown mica-schists of the Old Lizard Head Series, and to have affinity with the " porphyritic epidiorite dykes " that cut the Man of War gneisses (which, by the by, are typical coarse-grained gneisses). I have found these dykes, however, in the hornblende-schists also. They can be seen in fallen masses in Polbream Cove and in 1937 one was uncovered during agricultural work in a field in the hornblende-schist area on the left of the road leading from Pistil Ogo to Lizard Town. The map reference is 6 in. sheet lxxxiv S.E., 5 chains S.E. of the figure 2 on the 200 ft. contour-line. This outcrop was broken up and the pieces were stacked in the walls of the road, where they can still be seen. They afforded the freshest specimens. It appears likely too that a specimen in the Sedgwick Museum (21385), collected by the late Sir Jethro Teall at Laven-a-cean, on the west side of Housel Bay, may be from a junction of one of these dykes and hornblende-schist. On p. 111 of the Memoir an ophitic epidiorite is described as occurring as a boat-shaped mass in a small quarry on the top of Venton Hill Point. I have searched for this several times but have only found two small outcrops of one of these porphyrite dykes with fewer phenocrysts than usual.

The base of these dykes is hornblende and plagioclase. I cannot see any reason to suppose that the hornblende was derived from pyroxene. The plagioclase phenocrysts, which sometimes reach 5 mm. in length, are abundant and sometimes orientated to the margin of the dyke by flow. Extinction-angles and refractive index indicate that the felspar is andesine or between andesine and labradorite. A little apatite occurs and a black opaque mineral is common.

Examination of the Geological Survey slides of the dykes cutting the Man of War gneisses does not reveal any difference between these and the Polpeor dykes; and I feel sure that they are of the same age. The strong resemblance of all these dykes to the hornblende-schists makes me think that they are the last spurt of the magma that formed those rocks and that their intrusion into the Man of War gneisses indicates that the whole of the hornblende-schists are younger than the Man of War gneisses.

QUARTZ-DIORITE PEGMATITE VEINS.

Thanks to the courtesy of the Directors of the St. Keverne and Associated Quarries, Ltd., I have been able to see their old quarries between Porthoustock and Porthkerris Point and also a new quarry at Pedn Tiere (see 6 in. sheet lxxxi N.E.) where in 1937 two visits showed that very interesting rocks were exposed. The hornblende-schists here were invaded by a felspathic gneiss with folia of amphibole, but this rock is too decomposed for determination of all the minerals. This gneiss and the hornblende-schists were then cut by veins of a very striking rock with white felspar, large crystals of hornblende and small patches of quartz which can be picked out in hand-specimens with a lens. One of the hornblende crystals measured was 3 inches long but the average size is under an inch. I found a specimen of coarser quartz and felspar intergrowth with a little hornblende in which the quartz is abundant, and also a specimen from a vein with large crystals of quartz. Slides of the typical rock show that the quartz occurs as a fine mosaic. The felspar is all so much decomposed that it is hard to obtain any optical reactions, but in one slide polysynthetic twinning can still be seen and where the fresher felspar adjoins quartz the refractive index of the felspar is seen to be less than that of the quartz, which shows that it is oligoclase or albite. Zoisite occurs and one crystal was seen that is probably allanite. This rock seems to be quartz-diorite-pegmatite. It and the gneissose rock that preceded it as an intrusion into the schists are, like the hornblende-porphyrite dykes, best interpreted as final spurts of the magma that produced the rocks described here as primary hornblende-schists and gneisses, but the quartz in the pegmatite distinguishes this portion of the magma from that which consolidated as the hornblende-porphyrite dykes.

NOMENCLATURE.

In using these names " primary hornblende-schists and gneisses " I am laying myself open to the charge of being pedantic, but the term " gneiss " is usually applied to the coarser foliated rocks. In his *Structural and Field Geology* (1905, p. 77), James Geikie says that gneiss is sometimes fine-grained with thin and even foliation. This certainly applies to the Kennack gneisses, as far as the thinness of folia is concerned, and other rocks in The Lizard have been called gneiss that are fine-grained and only faintly foliated by flow. On the basis of James Geikie's definition and previous usage it would be correct to call all these hornblende-felspar rocks gneiss (as Mr. E. H. Davison has done in his *Handbook of Cornish Geology*), but I have introduced the word " schists " to show that there is considerable variation in grain, ranging from the relatively coarse Mullion rocks to the very fine-grained Cadgwith specimen.

The mineral composition of these hornblende-schists and the porphyrite dykes is dioritic, but their melanocratic nature, owing to the abundance of hornblende, makes the percentage of silica lower than that characteristic of diorites. On the other hand these rocks have not the mineral composition of typical gabbros. It is remarkable that neither the hornblende, the diopside, nor the felspar show good crystal outline, even when they occur as phenocrysts, but this may be due in whole or partly to flow in the magma under great pressure. The specimen I found near Caerthillian Cove with abundant hornblende phenocrysts could be called a camptonite but for the absence of the idiomorphism typical of the lamprophyres. These rocks could perhaps be reasonably called primary melanocratic diorite-gneiss, but it seems better and far simpler to use the prefix " hornblende ", which at any rate has the advantage of being descriptive of the most abundant mineral.

On the Glacial and Interglacial Marine Beds of Northern Lewis.

By D. F. W. BADEN-POWELL.

1. SCOPE OF INQUIRY.

THE Outer Hebrides, lying off the north-west coast of Scotland, are of particular interest to the student of Pleistocene geology, on account of the grand scale on which the results of ice-action are to be seen, and because of the marine shell-beds which are to be found at the northern end of the Isle of Lewis. In the present paper no general survey of the glacial deposits of the Outer Hebrides will be attempted; my object is rather to draw attention to certain features of the marine fossils, as a study of the coast sections shows that a faunal sequence can be established in the Pleistocene series.

My visits to Lewis were made in 1933 and 1935, in company with Mr. Charles Elton, and I am most grateful to him for his help and companionship in the field. In addition, I wish to thank Dr. Wilson Dougal and Dr. R. M. Craig for helpful discussions on the geology of Lewis, and the officials at the British Museum and the Geological Survey Museum for permission to borrow specimens and papers from their departments.

2. PREVIOUS RESEARCH.

Except for a brief reference to the drift as "alluvium" by Macculloch, our knowledge of the marine and glacial deposits of Lewis is due primarily to the work of James Geikie. His first paper (1873) on the glaciation of Lewis was followed later (1878) by a fuller description of the shelly drift, and his ideas were re-stated from time to time in the three editions of his book *The Great Ice Age* (1874, 1877, and 1894). Etheridge, who had visited Lewis with Geikie, published an account of the marine fossils from the drift of Northern Lewis (1876). The only further contribution to the subject during last century which I have been able to find was by Campbell (1873), who tried to prove that the ice had reached the Hebrides from the north-west, whereas Geikie claimed that it had come from the south-east.

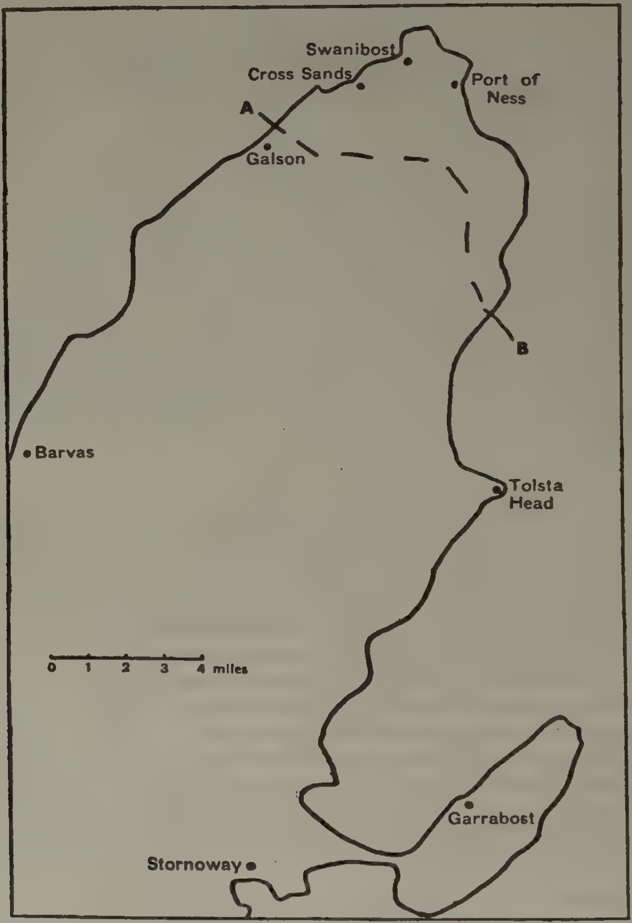
The main sequence proposed by Geikie as a result of his work was as follows:—

Upper Boulder Clay Interglacial Beds Lower Boulder Clay	(Northern Lewis).
Glacial Till . .	(Central Lewis).

Geikie's original idea that the till of Central Lewis is older than the sequence in the north seems to have been modified later on, but the important point is that he noticed the difference between the glacial deposits in the central and northern parts of the island.

Above all he was responsible for the discovery of the shelly drift near the Butt of Lewis and at Garrabost on the Eye Peninsula.

During the present century little has been added to Geikie's pioneer work. Wilson Dougal, who has many years' experience of the local geology, has added a third site for the shelly drift at Tolsta Head (Dougal, 1928), but unfortunately he did not give a detailed description. Panzer (1928) has raised several points of interest about the surface features of Lewis, including a suggestion of the existence of planes of marine denudation which had been formed prior to the maximum glaciation. The existence of a raised beach at Loch Maddy,



TEXT-FIG. 1.—Map of Northern Lewis showing localities mentioned.

in North Uist, was suggested by Gregory (1929), and Jehu and Craig (1934) have made a summary of previous work, and contributed valuable information about the distribution of certain types of glacial erratics, although their work was mainly concerned with the solid geology. As regards a raised beach which is considered to be of more recent age than the shelly drift, this was shown by Elton and myself (1937) to be older than sand dunes containing an Iron Age kitchen-midden at Galson Farm, and in a paper on a shelly clay near the shore of Loch Alsh (1937) I proposed an exact definition of the term Holocene, as applicable to the Loch Alsh deposit and to a similar marine deposit in Skye. Although this Loch Alsh site is not in the Outer Hebrides, it is mentioned here as it may be useful for future correlation.

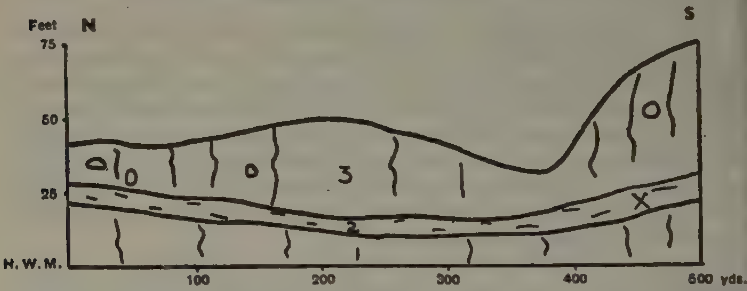
3. Coast Sections.

The names of most of the places mentioned in the present discussion on Northern Lewis will be found on the accompanying sketch-map (Text-fig. 1), and the spelling is that of the Ordnance Survey Map, Popular Edition, Sheets 8 (Butt of Lewis) and 14 (Stornoway). It will be seen from the sketch-map that the main sections described here are situated within a radius of three miles of the northern end of Lewis. As there are certain differences between the western sections near Swanibost and those on the east coast at Port of Ness, they will be described separately.

Sections on the West Coast.—The most northerly part of these sections are to be seen at Swanibost sands, and are shown diagrammatically in Text-fig. 2. They extend south-westward along the coast for a distance of about two miles to Cross Sands and the mouth of the Dell River. On first visiting the locality it is not easy to make out the sequence in the cliff sections, because they are much obscured by sand dunes, and there is frequently a veneer of the higher beds coming down over the face of the lower. After a longer acquaintance, however, it can be seen that the following sequence is constant for some distance down the coast. The lowest 15 or 20 feet of the cliff consist of rather stiff brown boulder clay, containing shell-fragments, this deposit resting on the pre-Cambrian rocks. Next one finds about 10 feet of shelly sand with occasional pebbles, resting on an eroded surface of the boulder clay. The height of this sand is from about 20 to 40 feet above the present beach. Superimposed on the sand is an enormous thickness of boulder clay which reaches to the top of the cliff. This upper boulder clay has a thickness of 40 to 50 feet in some places. Its lower part consists partly of brown stoneless silt, and its upper part is sometimes so stony that there is barely room for any matrix between the stones. On the whole, as Geikie points out, the boulder clay above the sand is more gritty and sandy than the lower boulder clay. Whole shells and shell-fragments occur in this upper boulder clay, and there are also patches of what appear to be the intermediate sand caught up as erratics in the upper deposit.

The "veneer" mentioned earlier usually consists of part of the upper boulder clay forming a cemented facing to the sand, and some digging had to be done to clear the junction of these deposits.

At the southern end of Swanibost Sands, immediately south of the place called Traigh Chumil on the one-inch map, and marked with an "X" in Text-fig. 2, the sections are clearer, and the sand between the two boulder clays is extremely fossiliferous at this point. The most abundant shell is a small stout *Sipho*, and *Aporrhais*, *Trophon*, and *Bela* are also common. As will be shown later the fossils here indicate both warmer and colder climatic conditions than those of to-day. The thickness of the sand at this point is 10 feet, and the shells were restricted to the upper 6 feet of the deposit. The top of the sand was found (by hand-level) to be 24 feet above present high water-mark, which was taken as the highest point at which seaweed was growing on the rocks. As half the present tidal range on this coast is about 5 feet, the height of the top of the sand is 29 feet above mean tide.



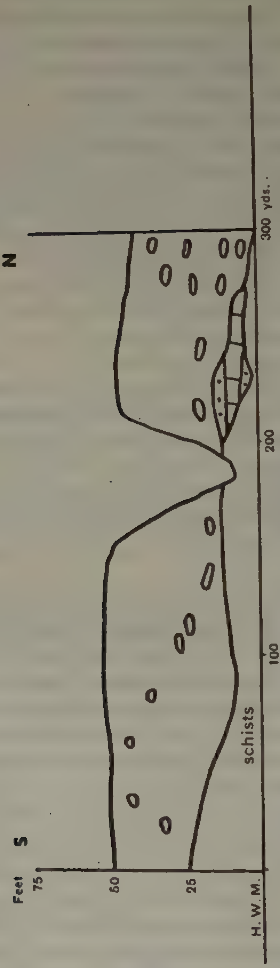
Text-fig. 2.—Coast Section of Pleistocene Beds at Swanibost, Northern Lewis. 1 = Lower Boulder Clay; 2 = Interglacial Marine Bed; 3 = Upper Boulder Clay; X = Fossiliferous locality.

The headland between Swanibost Sands and Cross Sands shows sections mainly in the upper boulder clay, but they are very inaccessible. In Cross Bay sections show much the same sequence as in Swanibost Bay, except that the stoneless silt appears below the shelly sand instead of above it. The sand deposit can be traced almost to the mouth of the Dell River; unfortunately time did not allow me to follow it beyond that point. The sand is occasionally fossiliferous, though never to the same extent as at the southern end of the Swanibost section. At Cross Bay *Dentalium* and *Turritella* are the commonest shells. There is no doubt that the shelly sand represents a marine deposit which is intermediate in age between the two boulder clays, and in order to facilitate reference to these deposits they will be referred to as the Lower Boulder Clay, the Interglacial Marine Bed, and the Upper Boulder Clay. A "cold" fauna including *Astarte borealis* and *Mya truncata* var. *uddevallensis* was found in the Upper Boulder Clay, but did not occur in either of the lower deposits

As regards the glacial erratics no difference was found between the three deposits. Most of the stones in the two boulder clays, also those which occur in the marine sand, consist of local metamorphic rocks, but occasional erratics of Torridonian sandstone are found in both boulder clays and in the Interglacial Marine Bed. It is possible that beds of more than one age are involved in the Upper Boulder Clay. Geikie (1878, pp. 865–6) appears to have had some such idea, with a hint of "shelly sand", "which . . . overlies the glacial deposits, and reaches to a height of 80 feet or so above the sea." I was unable to find this deposit, but at the northern end of Swanibost Sands, north of the mouth of the Swanibost River, the Upper Boulder Clay appears to pass laterally into a bed with mostly rounded pebbles and a sandy matrix. The base of this deposit is about 30 feet above meantide level, and no shells were found in it. It is difficult to make out its exact relation to the Upper Boulder Clay; it is tumultuous rather than bedded. A similar deposit was also seen on the coast immediately north of Barvas, and again at Port of Ness, where it will be referred to as the Glacial Marine Bed.

Sections on the East Coast.—The exposures described here occur immediately south of Port of Ness, and are shown diagramatically in Text-fig. 3. Etheridge and Geikie were not able to give so much attention to this section as to those on the west coast (Etheridge, 1876, p. 552), but Geikie (1878, p. 824) noticed that the large number of boulders here contrasts "somewhat strongly with their equivalent on the other side of the island". They did not have time to collect shells on this side.

The main coast section here extends for about 300 yards, but continuity is interrupted in many places by growth of turf and bushes. At the southern end the whole section from the top of the metamorphic rocks to the top of the cliff consists of massive purple-coloured silt, with occasional irregular stone beds. The silt shows little or no sign of bedding, and contains shells scattered through its mass, and its height above the present beach is from 25 to 50 feet. It is difficult here to measure heights above mean tide, as high-water mark is ill defined, but it is safe to say that the silt at this point reaches a height of at least 55 feet above mean tide. This silt can be traced as far as the southern jetty at Port of Ness, but its stoniness increases northwards until it has changed into a deposit of boulders and gravel with a silty matrix. This change occurs gradually throughout the 300 yards of outcrop. Shells were only found in the southern, silty end of the sections, and belong essentially to a "cold" type of fauna, with *Astarte borealis*, *Macoma calcarea*, and *Mya truncata* near to var. *uddevallensis*. This fauna shows marked differences from the interglacial fauna of the west coast, and is in fact like that of the Upper Boulder Clay or Glacial-marine fauna at Swanibost. The silt, specially where it passes laterally into heavy gravel, also resembles he similar facies at the top of the Swanibost sections. Pebbles which appear to have come from the local schists predominate, but erratics of Torridonian rocks also occur and, as Geikie observed, seem to be more common in the Port of Ness section than on the west coast.



Text-fig. 3.—Coast Section south of Port of Ness, Northern Lewis, showing Glacial Marine Bed overlying sands and boulder clay.

At one point the following section shows a series of deposits lying in a large hollow in the surface of the schists, with the silt continuing unconformably across the top of them :—

	Approximate thickness.
Sand and gravel	5 feet.
Boulder clay	6 ,,
Sand and rounded shingle . . .	5 ,,

As no fossils were found in these sandy beds under the silt, it is not possible to correlate them by direct palaeontological means with the Interglacial Marine Bed at Swanibost, but as the shingle at the base of the section here looks very like the Interglacial Marine Bed, it would seem that the silt deposit is at least associated with the Upper Boulder Clay glaciation, and may perhaps be slightly younger. The strong unconformity between the silt deposit, which will be referred to as the Glacial Marine Bed, and the underlying series is shown in Text-fig. 3.

It is not easy to see how the silt was formed, but it seems to consist of the matrix of a boulder clay rearranged in some way. The marine shells in the silt were not seen in place of growth, but their comparative abundance suggests that the silt in some sense a marine deposit. One must admit that the lack of bedding both in the silt and in its stony facies is against the idea of undisturbed deposition in water, but the climate represented by the shells is so distinctly cold, that contemporaneous disturbance by some form of floating ice seems a possible explanation. In case the silt is eventually proved to be a marine bed more or less in place, it should be stated that the highest point at which the silt was observed was about 60 feet above mean tides. At several points along this coast the Pleistocene series is capped by blown sand, which can be distinguished from any of the older Pleistocene sands as it consists almost entirely of comminuted shell-fragments.

4. Faunal Sequence.

In the following faunal list I have included the shells identified by Etheridge (1876) with those found by myself, and those marked (*) are the species reported by Etheridge, but not found by me; those marked (**) were found by both of us. I have made a careful comparison between Etheridge's collection, which is at the British Museum, and my own, which is at the University Museum, Oxford. Two species which were reported by Etheridge, *Leda pernula* and *Astarte crebricostata*, were not found in his collection. In the present list, a " C " before a generic name indicates that that species is now found in colder seas than those surrounding the Hebrides; those with " W." indicate a warmer climatic equivalent. The initials at the head of the columns are used as follows:—

L.B.C. = Lower Boulder Clay.
I.M.B. = Interglacial Marine Bed.
U.B.C. = Upper Boulder Clay.
G.M.B. = Glacial-marine Bed.

Foraminifera.	L.B.C.	I.M.B.	U.B.C.	G.M.B.
Triloculina oblonga Montagu* . .	—	×	—	—
Quinqueloculina seminulum L.* .	—	×	—	—
Dentalina communis d'Orbigny* .	—	×	—	—
Truncatulina lobatula Walker* . .	—	×	—	—
Truncatulina refulgens Montfort* .	×	—	—	—

		L.B.C.	I.M.B.	U.B.C.	G.M.B.
	Nonionina asterizans Fichtel and Moll*	—	×	—	—
	Nonionina depressula Walker and Jacob*	—	×	—	—
	Polystomella crispa Linné*	—	×	—	—
	? *Polystomella striatopunctata* Fichtel and Moll*	×	—	—	—
	ECHINOIDEA.				
	Unidentified spines	—	×	—	—
	ANNELIDA.				
	Serpulids	—	×	—	—
	BRYOZOA.				
	Salicornaria Sp.*	—	×	—	—
	LAMELLIBRANCHIA.				
	Anomia Sp.	—	×	—	—
C.	*Chlamys islandicus* Müller**	—	×	—	×
	Leda minuta (Müller)	—	×	×	—
C.	*Leda pernula* Müller*	—	?	—	—
	Leda pygmaea (Münster)	—	—	—	×
	Astarte sulcata da Costa**	?	×	—	—
	Astarte elliptica Brown	—	×	×	×
	Astarte montagui Dillwyn**	×	×	×	×
	var. *striata* Møller	×	—	—	—
C.	*Astarte borealis* Chemnitz	—	—	×	×
C.	*Astarte crebricostata* Forbes*	—	?	—	—
	Cyprina islandica Linné**	×	×	×	×
	Cardium echinatum Linné**	—	×	—	—
	Cardium exiguum Gmelin	—	×	—	—
	Dosinia lincta (Montagu)	—	×	—	—
	Spisula solida (Linné)**	—	×	—	—
C.	*Macoma calcarea* Chemnitz**	—	?	—	×
	Corbula gibba (Olivi)	—	×	—	—
	Mya truncata Linné*	—	×	—	×
C.	var. *uddevallensis* Hancock	—	—	×	—
	Saxicava arctica Linné var. *pholadis* Linné	?	—	—	×
	Panomya norvegica (Spengler)*	—	—	×	—
	SCAPHOPODA.				
	Dentalium ? entalis Linné**	×	×	×	×
	GASTEROPODA.				
	Emarginula ? fissura (Linné)	—	×	—	—
	Calliostoma conuloide (Lamarck)	—	×	—	—
	Lacuna pallidula (da Costa)	—	×	—	—
	Lacuna vincta (Montagu)	—	×	—	—
	Rissoa ? membranacea Adams	—	×	—	—
	Onoba strita Adams	—	×	—	—
	Turritella communis Risso**	—	×	—	—
	var. *tricarinata* (Brocchi)	×	×	×	—
	Aporrhais pes-pelicani Linné**	—	×	—	—
	Scalaria trevelyana (Leach)	—	×	—	—
	Trivia europaea (Montagu)	—	×	—	—
	Natica groenlandica Beck	—	—	—	×
	Natica alderi Forbes*	—	×	—	—

	L.B.C.	I.M.B.	U.B.C.	G.M.B.
Natica montagui Forbes*	—	×	—	—
W. *Ocenebra erinacea* (Linné)	—	×	—	—
Nassa incrassata (Ström)	—	×	—	—
Buccinum undatum Linné**	—	×	—	—
Purpura lapillus Linné	×	—	—	—
W. *Sipho jeffreysianus* (Fisher)	—	×	×	—
C. *Trophon clathratus* (Linné)**	—	×	—	—
Trophon truncatus (Ström)*	—	×	×	—
Trophon barvicensis (Johnston)	—	×	—	—
Bela turricula (Montagu)	—	—	—	—
var. *rosea* (Loven)	—	×	—	—
var. *ecarinata* Sars	—	×	×	—
Bela trevelyana (Turton)	—	×	—	—
Raphitoma nebula (Montagu)	—	—	—	—
var. *elongata* Jeffreys	—	×	—	—
Mangelia costata (Donovan)	—	×	—	—
Admete viridula (Fabricius)	—	×	—	—
CIRRIPEDIA.				
Balanus ? balanoides Linné*	—	×	×	×

Notes on Identification.—The foraminifera in this list are given as published by Etheridge (1876, p. 553). No attempt has been made to revise their nomenclature, and I was not able to add to this list myself. The echinoid spines and serpulids were seen to occur rarely in the Interglacial Marine Bed, when it was searched for small shells. *Salicornaria* is recorded on the authority of Etheridge (1876, p. 553). The occurrence of *Leda pernula* has been entered on the list as doubtful, as there are no shells belonging to this species in Etheridge's collection at the British Museum, and the same applies to *Astarte crebricostata*. Unless these two forms are found during future work they should perhaps be deleted from the list. Etheridge recorded *Cardium edule* from the Interglacial Bed at Swanibost. The hinge fragment under this name at the British Museum (No. 97958) appears to me to be *Cardium echinatum*, as comparatively wide troughs can be seen between the ridges, but this identification is uncertain. One fragment of *Cardium edule* found by me was not in situ, and therefore this species has been omitted provisionally from the list. I have confirmed Etheridge's identification of *Natica alderi* and *Natica montagui*; in addition to these, I found a large number of *Natica* which were too young for definite identification, but some of them may belong to *clausa* Broderip and Sowerby. The most interesting species in the Interglacial Bed is the *Sipho* which is abundant in the shelly patch at the southern end of Swanibost Sands. This agrees well with *Sipho jeffreysianus* in the Recent collections at the British Museum, and also with Harmer's figures and descriptions of this species, and with Jeffrey's *Fusus buccinatus*, which he later referred to *jeffreysianus* (*British Conchology*, vol. 5, p. 219). Some less perfect specimens than mine are exhibited in the British Museum under the name *Tritonofusus propinquus* (No. 97965), and one of these was figured by Harmer (*Pliocene Mollusca*, pl. 38, fig. 8) as *Sipho islandicus*, but his identification (p. 374) was provisional, and I am sure that Harmer would have agreed to the name of *jeffreysianus* if he had seen the less broken specimens which I was fortunate enough to find.

Climatic Equivalent of the Lower Boulder Clay.—It can be seen from the list that no shells of a specially cold or warm character have been recorded from the Lower Boulder Clay. This fact is interesting, because this deposit was undoubtedly formed under thoroughly cold conditions. The presence of *Purpura lapillus*, represented by one fragment, suggests that the marine material picked up by the ice was from the tidal zone, and certainly no deep-water forms were found. The presence of Torridonian rocks suggests that the ice which brought this boulder clay came from the mainland of Scotland, but much work remains to be done on this subject.

Climatic Equivalent of the Interglacial Marine Bed.—It is at once obvious that the mixture of the cold forms *Chlamys islandicus*, *Macoma calcarea*, and *Trophon clathratus* with the warm species *Ocenebra erinacea* and *Sipho jeffreysianus* makes it impossible to work out the present climatic equivalent of this deposit. The three cold forms now inhabit Scandinavian seas, and although *Ocenebra erinacea* is known to occur at present off Southern Norway, it is not common as far north as this, and off Western Scotland its present distribution seems to be farther south than Lewis; both Jeffreys and Harmer agree that *Sipho jeffreysianus* is a still more southern form, and is only found living off Southern Britain. My first idea about this problem was that the warm and cold forms might be found in separate layers in the same deposit, but collection layer by layer soon proved that this was wrong: *Trophon clathratus* and *Sipho jeffreysianus* undoubtedly occurred together in the same shelly seam. It should also be remembered that all the shells at the most fossiliferous locality came from a thickness of only 6 feet of sand.

Various explanations occur to one's mind: for instance, the cold forms might be derived, and the warm forms would then represent the true fauna, but although only fragments were found of the cold shells *Chlamys islandicus* and *Macoma calcarea*, the shells of *Trophon clathratus* do not appear to be more broken or water-worn than is usual in a marine deposit. It appears to be true that the warm forms came into the district as colonizers after the Lower Boulder Clay glaciation, because the *Sipho* at least is abundant in the fossiliferous part of the Interglacial Marine Bed, but is unknown from the Lower Boulder Clay. It seems more probable, therefore, that the cold forms were able to survive for a time and mingle with the warm immigrants. Whatever the explanation of this mixture of warm and cold forms it must be accepted as a characteristic of this deposit, but this example does not invalidate the principle of the "climatic equivalent" method in general, because that still works perfectly for the later Glacial-marine Bed. It should be stated that the mixture of climatic types is not unique in this example, but is also found in Pleistocene deposits in other parts of Britain. The arrival of the warm species at this stage justifies the application of the term "interglacial" to this deposit.

With the one exception of *Cardium edule*, of which the occurrence is doubtful, the Interglacial Marine Bed represents deposition in rather deep water. Following Lloyd Praeger's method for estimating depth or deposition, that is by calculating the mean minimum depth at which the most common fossil forms in the deposit now live, the depth of water was not less than 4½ fathoms (27 feet), and was probably considerably greater. Adding to this the present height of the deposit above mean tide, about 29 feet, a minimum estimate for submergence at this stage is 57 feet (about 17 m.). As the shore-line of this deposit has not yet been seen as a raised beach, the exact amount of submergence is not known, but some of the rarer shells found, such as *Admete viridula*, also confirm deep-water conditions. A submergence of 17 m. is only a minimum estimate : from a general consideration of the fauna as high a figure as 60 m. is possible.

Climatic Equivalent of the Upper Boulder Clay.—The beds discussed in this paragraph are those on the west coast at Swanibost only, and as it has not yet been possible to differentiate between the true boulder clay and the Glacial Marine Bed on that coast, part or most of the fauna may really belong to the Glacial Marine Bed. The only warm element in this fauna is represented by one shell of *Sipho jeffreysianus*, but this is almost certainly derived from the Interglacial Marine Bed, erratics of which are caught up in the Upper Boulder Clay. The contemporaneous fauna includes the cold forms *Astarte borealis*, *Mya truncata* var. *uddevallensis*, and *Panomya norvegica*, which appear to represent immigrants which had not yet invaded the district while the Interglacial Marine Bed was being laid down.

Climatic Equivalent of the Glacial-marine Bed.—The fauna of the great bed of stony silt at the top of the Port of Ness sections on the east coast has a definitely cold character ; its present climatic equivalent is to be found off the Norwegian coast, if anything, that of Northern Norway. The characteristic forms are *Chlamys islandicus*, *Astarte borealis*, *Macoma calcarea*, and *Mya truncata* near to var. *uddevallensis*. In addition the more temperate forms of the Interglacial Marine Bed have disappeared. It must be admitted that this faunal assemblage is one which would be expected during any cold period, but since the cold fauna occurs so distinctly at the top of both the Swanibost and Port of Ness sections, it seems reasonable to assume that they are contemporaneous. The detailed relation between the Upper Boulder Clay and the pure Norwegian fauna needs further study in the field, but from the general point of view of the faunal sequence, it is certain that the northern assemblage of the Glacial Marine Bed is younger than the mixed fauna of the Interglacial Marine Bed.

5. Correlation.

The more difficult question of the possible correlation with Pleistocene marine beds elsewhere must be mentioned briefly. In attempting to trace the distribution of the Interglacial Marine Bed one would expect to find remnants of this deposit in other parts of Lewis. Only two localities have been recorded where such remnants may exist. On Tolsta Head, on the east coast between Port of Ness and Stornoway, Dougal (1928, p. 17) discovered a bed of clay "at a hundred feet above sea level" containing "*Turritella*, *Astarte*, and other bivalve fragments". Unfortunately I was not able to investigate this deposit. Then both Geikie (1878, pp. 826–7) and Dougal (1928, p. 17) mention the occurrence of marine shells at Garrabost, about 6 miles east of Stornoway. I found the Garrabost brickworks closed and the section overgrown, but on the edge of the cliff north of the village some very poor sections were visible (in 1935), showing shelly sand beneath a red boulder clay. According to the six-inch map, the height of this site above ordnance datum level is 125 feet (about 38 m.). The following shells were found in the sand :—

Chlamys islandicus Müller.
Astarte borealis Chemnitz.
Cyprina islandica Linné.
Mya truncata Linné.
Turritella communis Risso.
? *Aporrhais* Sp.
Bittium ? *reticulatum* (da Costa).
Balanus Sp.

This assemblage might possibly be referred to a shallow-water facies of the Interglacial Marine Bed, but if this is correct *Astarte borealis* must be added to the known fauna of that deposit. The sections were too obscure to find out whether the sand is in place or whether it is an erratic in the red boulder clay, and time did not permit any digging.

It is not easy to trace either the Upper or Lower Boulder Clays far from the northern end of Lewis. Geikie (1873, p. 538) described the "bottom till of the low ground" of Central Lewis as consisting of a gritty deposit containing little clay in its matrix, and distinguished it from the true boulder clays at Swanibost and Port of Ness. In a large number of sections on the road between Stornoway and Barvas, along nearly all the larger streams, as well as in coast sections, this drift has a queer green tinge in its matrix and, as far as I could see, contains no erratics of Torridonian sandstone or arkose, thus differing from the boulder clays farther north. The boundary between this type of drift and the Upper and Lower Boulder Clays of the northern sections is indicated on the sketch-map (Text-fig. 1) by the line A—B, the boulder clays with Torridonian erratics occurring only north of this line. As far as my experience goes, this boundary is correct for the west coast, meeting it near Galson Farm, but on the east coast it may be shown by future work that the line should be taken farther north. Jehu and Craig, however, claim to have found Torridonian erratics in the drift south of this line, near Barvas (1934, p. 872).

The question of the age-relation of the two types of drift is important. Small green patches occur in the "Torridonian Boulder

Clay " at Port of Ness, and an occasional Torridonian pebble can be seen in the drift with the green matrix within a mile or so of the boundary. As the two types of drift were never seen in superposition in a section, it seems almost certain that the green type passes laterally into one or both of the northern boulder clays, and if my interpretation of the Port of Ness section is correct, I am inclined to think that it is the Upper Boulder Clay which is continuous and contemporaneous with the green type, but further evidence is needed on this point. In this connection it is interesting to remember Panzer's opinion (1928, pp. 194–6) that platforms of marine erosion backed by ancient cliff-lines appear to exist over parts of the Lewis plains, especially at the approximate levels of 60 and 30 m. Panzer does not mention any marine deposits on these platforms, nor did he apparently visit the fossiliferous deposits of Northern Lewis, but he makes the important observation (p. 196) that the 60 m. platform has been polished and striated by the ice which was responsible for laying down the ground moraine of Central Lewis. Unfortunately I have not examined these platforms myself in the field, but I am inclined to think it is quite possible that one or more of these features observed by Panzer may have been formed by the sea in which the Interglacial Marine Beds were laid down. If this opinion is correct it agrees well with the idea that the glaciation responsible both for the " green " boulder clay and for the Upper Boulder Clay was later than the Interglacial Marine stage.

The apparent discrepancy of heights is not as great as it might seem to be. The submergence of 56 feet (17 m.) suggested by the shelly sand near Swanibost is an absolutely minimum estimate; that is the nature of the fauna suggests at least that degree of submergence; but the assemblage could equally well represent a submergence of some 60 m.

6. Sequence of Events.

The main considerations which emerge from this work are that the Pleistocene marine fauna seems to have had the following history as far as Northern Lewis is concerned :—

(1) The Lower Boulder Clay seems to be a product of land-ice, and as the shells in that deposit are temperate in character they are presumably derivative.

(2) There followed a period of submergence of at least 56 feet (about 17 m.), and possibly of greater amount, when the Interglacial Marine Bed was laid down. At this time such warm forms as *Ocenebra erinacea* and *Sipho jeffreysianus* invaded the district, but may have been able to live together with a cold fauna, including *Trophon clathratus*.

(3) After a period of considerable erosion, represented by an unconformity, renewed glaciation was responsible for the deposition of the Upper Boulder Clay. At least in part this deposit seems to be

a product of land-ice, which may have acted during a period of emergence, as the boulder clay descends at least to present-day sea level.

(4) Either during or later than this stage the marine fauna is cold in character, the interglacial fauna having disappeared. It includes *Chlamys islandicus*, *Astarte borealis*, *Macoma calcarea*, and *Mya truncata* var. *uddevallensis*, and if the deposit in which these shells are found has not been removed far from its original level, the degree of submergence may be about 60 feet (about 18 m.).

(5) I have indicated elsewhere that the clays at Allt Udalain, on Loch Alsh and at Loch na Dal in Skye contain a fauna of Holocene rather than Pleistocene character, and that the amount of submergence at that stage was not more than about 25 feet (about 8 m.) (Baden-Powell, 1937, pp. 279–280). It is possible that a raised beach at Galson and another near Stornoway may also be Holocene in age (Elton and Baden-Powell, 1937, pp. 360–4).

The strongest characteristics of the Holocene of North-Western Scotland seem to be that the fauna is almost the same as the local living fauna, and that submergence did not exceed 25 feet (about 8 m.) (Baden-Powell, 1937, p. 281). The fauna of the Interglacial and Glacial Marine Beds of Northern Lewis do not conform to those conditions, and I would define them as Pleistocene since they represent climatic conditions differing markedly from those of the present day, and incidentally the degrees of submergence were greater than during the Holocene. If in the future correlations are attempted between the marine beds of Northern Lewis and similar deposits elsewhere, the faunal sequence within the Pleistocene should prove useful for such work.

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Post-glacial Foraminifera from the English Fenlands.

By W. A. Macfadyen.

THERE are three principal types, peat, fen clay (otherwise called blue buttery clay), and silt, in the post-glacial deposits of the Fenlands, which lie mainly within the shires of Cambridge and Lincoln, and Norfolk. It has long been known that Foraminifera occur in the silt and clay. The genus *Lagena* was recorded from the silt by Williamson in 1848, with twelve species from March, and sixteen species from Boston. In 1865, Parker and Jones listed thirty-five species of various genera from four samples of sub-Recent clay and silty clay from near Peterborough, Boston, and Wisbech. In 1870, H. B. Brady described the living brackish water Foraminifera from our coasts, and compared them with those recorded from the sub-Recent Fenland deposits by Parker and Jones. In a footnote (p. 306) he added the record of eight more species, so he presumably had a private communication from these authors, or himself studied further material. In 1881, James Green in two short papers noted the occurrence of abundant Foraminifera in layers of the March roddon, and figured nine species therefrom.

In 1932, the writer began to investigate the microfauna of these clays and silts in connection with the activities of the Fenland Research Committee and since then sixty-one samples have been examined, forty-two of the clays and nineteen of the silts. In them have been recorded some 116 indigenous species of Foraminifera (108 from the silts and sixty-seven from the clays); fifteen species derived from the Cretaceous (ten from the silts and ten from the clays); and thirteen species derived from the Jurassic (one from the silts and twelve from the clays). The results may be summarized as follows:—

No. of samples considered.	*Numbers of species and varieties of Foraminifera recorded in any one sample.*			
	Indigenous.		*Derived.*	
	Limits.	*Average.*	*Limits.*	*Average.*
42 clays .	0—35	9	0—9	2
13 silts .	20—62	37	1—6	4

The figures are taken from only thirteen silt samples, since the examination of the remaining six has not been completed. In every case where high numbers of indigenous species have been found in clay samples, the washed residue contained much silt.

The Foraminifera can be distinguished as either indigenous, or derived from the Cretaceous and Jurassic, mainly by the known range of the species, and this can often be confirmed by their state of preservation. The Jurassic species are often characteristic, and usually very well preserved, sometimes as empty shells, and of a dark colour. The Cretaceous species are well-known chalk forms with the opaque white infilling and matrix that are familiar in the Chalk Foraminifera. The indigenous sub-Recent forms are usually empty shells very well preserved, the species and often the appearance being those of the present-day coastal fauna.

CONDITIONS OF DEPOSITION.

Before discussing the further distribution of the Foraminifera attention must be given to the formation of these Fenland deposits. Dr. Godwin's recent paper represents very well the present opinion. In this view the low-lying fen country was intersected by a reticulation of water channels, which were largely tidal. Silt was thrown down in the channels and along their banks, so that the waterways eventually occupied the top of low ridges, as is commonly the case in deltas. When occasional high tides caused the channels to overflow, estuarine water with its silt and the accompanying Foraminifera penetrated the lagoons in which the fen clay was being laid down. On the drying of the land the silt ridges became what are now known as roddons.

It is thus explained why the fen clay nearly always carries more or less silt, which brought with it both derived Cretaceous Foraminifera and indigenous species of estuarine type. The "indigenous" Foraminifera found in the clays are thus a mixture of the estuarine forms brought in when the tidal channels overflowed, and of the species which found it possible to live in the considerably fresher water of the lagoons. The difficulty is to distinguish between these two groups, since various species commonly live in both environments. However, to a limited extent this does seem possible by studying the frequency of occurrence of the different species in the clay samples.

THE DERIVED FORAMINIFERA.

The Jurassic Foraminifera appear mostly to have come from Jurassic clays exposed in post-glacial times close to where the derived fossils are now found. Where the sub-Recent deposits rest directly upon a soft Jurassic bed rock, e.g. Kimeridge Clay, the lower strata may contain an appreciable number of derived Jurassic Foraminifera. Their occurrence in the deposits is thus only occasional, and seems mainly to depend on the fulfilment of the above conditions.

The Cretaceous Foraminifera, most commonly of a few minute species, are a constant feature of the silt. They seem to have been brought up the channels from the coast, with the silty, estuarine, tidal water. They may have come directly from the erosion of actual outcrops of the chalk, or as Professor Swinnerton has pointed out to me, secondarily from the Chalky Boulder Clay. The Cretaceous Foraminifera in the fen clay samples seem to be correlated with the contamination of silt.

THE INDIGENOUS FORAMINIFERA.

These yield evidence on three matters :—

(1) *The Age of the Deposits.*—This is so geologically recent that no species definitely known to be extinct has been found. The Foraminifera, however, do not yield more detailed evidence of the relative ages of the different beds.

(2) *The Climate.*—This did not differ sufficiently from that now existing for Foraminifera indicative of either warmer or colder conditions to be present. The single specimen of *Globigerina pachyderma* (Ehrenberg) found at Ugg Mere, Whittlesey, an indicator of somewhat colder conditions, can hardly be taken to challenge this finding.

(3) *The Salinity of the Water in which they Lived.*—Considerable information on this point is given. They seem to be useful indicators of salinity, ranging from purely marine conditions to practically fresh water. Foraminifera are typically marine in their habitat, though many genera and species will tolerate an admixture of fresh water. Fortunately the different shallow water forms that are found upon this English coast show different degrees of tolerance, so that a rough scale may be constructed, that will give some indication of the degree of salinity of the water in which they lived.

Brady's paper of 1870 contains the first beginnings of a foraminiferal salinity scale that I have found in the literature. The present work has enabled somewhat more detailed results to be obtained than those described by Brady, but on account of difficulties noted below, the results are so far only provisional. For instance there is as yet no precision as to the limits of salinity under which the different forms will live and it may be that the grouping given in Table A (below) will have to be altered as more information is obtained. Considerable further work will be necessary to establish the scale firmly; the salinity of a large number of brackish waters where Foraminifera are living must be determined by chemical analysis (a titration to estimate the chloride content might be adequate), and the faunas identified. This should make possible a quantitative scale to replace the present relative scale.

TOLERANCE OF BRACKISH WATER OF THE FORAMINIFERAL FAUNA.

Brady confined his discussion to the tolerance of brackish water of various genera, remarking that: " Our analysis need not extend to details respecting species, which may be gathered from the

Table. . . .” While agreeing with Brady’s view that the question of tolerance is in part a generic character, the present work points to the at least equal importance of the species.

On the results of an analysis of the Foraminifera recorded from thirty-four[1] fen clay samples, it seems possible to arrange certain commonly occurring species in order of their increasing tolerance of admixed fresh water. The division into five groups, III–VII, given below in Table A, is arbitrary, and based simply upon the number of samples in which each species is found, though the more tolerant groups, V, VI, and VII, seem to form natural divisions. In this table are considered only species that have been recorded from at least three samples of clays and silts combined. This method of consideration is not really satisfactory, since the results will depend upon the sampling, and the unknown degree of salinity represented by each sample. If the sampling be not comprehensive, and it will not be so unless a very large number of varied samples be taken, then the numerical results will be affected by the incomplete sampling. Meanwhile, such results as appear possible must be extracted from the available material.

Of the wholly intolerant (purely marine) Foraminifera, which may be called group I, that live off this coast, there is, of course, no evidence in the material studied. The most noteworthy absentee, which confirms Brady’s finding, is *Elphidium crispum* (Linné), which is generally abundant round our coasts. *Quinqueloculina seminulum* (Linné) is also remarkably absent; this is the more inexplicable since Brady recorded it, sometimes as common, in fourteen out of his thirty-two brackish samples.

Group II includes nine species that occur in the silts but have not been found in the clay samples. They have presumably little tolerance, though a little greater than members of group I.

Of group III with twenty-four species, it is impossible to judge from the present evidence which are really more tolerant than group II, and which have been merely introduced with the silt and killed by the fresher water of the lagoons.

Group IV has eight species which are more commonly found in the clays, and there is little doubt that they survived and multiplied in the conditions obtaining.

In the case of group V with seven species, group VI with four species, and group VII with two species, there can be no doubt that the forms lived increasingly successfully under fresher water conditions.

Table B, extracted from Table A, shows more clearly the difference in tolerance between various species of the same genus, insofar as this has been deduced from the above-mentioned premises. Of particular note is that the relative abundance of a species of *Trochammina* (as distinct from its frequency of record), is often greater in the clay samples than in the silts in the cases of *T. inflata*, *T. macrescens*, and *T. squamata*, and equal in the case of *T. ochracea*. This suggests that certain species of this genus definitely prefer a brackish water habitat to purely marine conditions.

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[1] The remaining eight samples either contained no indigenous Foraminifera or were otherwise unsatisfactory.

A point of interest that emerges is that in the genera *Discorbis*, *Nonion*, *Elphidium*, and *Trochammina*, the species that are recorded as more tolerant of fresh water admixture seem to have the lateral margins of the test well rounded, whereas in the less tolerant species the margins are acute.

It must be emphasized that the tables are only provisional. The material on which they are based is not adequate for any finality.

If Brady's list of brackish water Foraminifera from his thirty-two samples be analysed on the same basis, it is found that of his seventy-three recorded species only thirty-seven are listed from three samples or more. Comparison with the present Fenland fauna shows that there are certain well-marked agreements, and some equally striking differences. Some of the latter are probably due to incompletely representative sampling in both cases. Agreement is most marked in groups V, VI, and VII, tolerating the greater proportions of admixed fresh water, where most of the species are common to both lists. Conversely, of species which either do not occur or are extremely rare in the Fenland deposits, Brady records *Haplophragmoides canariensis* (d'Orbigny) in 47 per cent, and *Quinqueloculina seminulum* (Linné) in 44 per cent of his samples. Among the most noteworthy omissions of common Fenland species from Brady's list are *Discorbis obtusus*, *Lagena lucida*, and (practically) *Trochammina squamata*.[1] The result of the comparison suggests that the average of Brady's samples represents conditions to some extent intermediate between those recorded by the Fenland clays and the silts.

OTHER MICROFAUNA AND MICROFLORA.

Brady (p. 275) found the normally fresh-water living Rhizopods of the Difflugian type, " . . . increasing in number as the Foraminifera diminish, until, in fresh water, the *Difflugiae* and their immediate allies become the representatives of the testaceous group." Cushman (p. 62) states that they are unknown as fossils, but I have found *Difflugia oblonga* Ehrenberg, *D.* sp., and *Centropyxis* sp. in the March roddon silt, and the last-named also at Ugg Mere, Whittlesey. Their tests are to be found to-day in various English streams and ponds, but what may be their tolerance, if any, of admixed sea-water, I have no information.

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[1] Of this species Brady records and figures a single alleged specimen from a locality in the Hebrides.

Associated with the Foraminifera there are certain other fossils that are useful as salinity indicators. Fine echinoid spines and a Polyzoan, seem to characterize marine or estuarine conditions with very little fresh water admixture. They are sometimes found in company with Foraminifera of group II.

Ostracods of several unidentified species are common in many samples. Without closer identification they are valueless as a guide to salinity. They are found about twice as frequently in the silts as in the clays, so that they appear to flourish in estuarine conditions; but a number of species also flourish in completely fresh water, and are to be found abundantly in some English streams, and in ponds.

Four large species of Diatoms are commonly encountered when searching for Foraminifera. They have been kindly identified by Mr. N. Ingram Hendey, F.L.S., as—

Campylodiscus costatus Wm. Smith.
Eupodiscus argus Ehrenberg.
Triceratium favus Ehrenberg.
Melosira arenaria Moore.

They occur more frequently and more abundantly in the silts than in the clays, *Eupodiscus argus* most noticeably so.

There is found an unidentified fossil which sometimes occurs in thousands. It is a hollow, transparent or translucent brown, tailed globe, sometimes collapsed, about 0·15 mm. in diameter. It occurs in a similar proportion of samples of both silt and clay, but more abundantly in the clays. However, Mr. Arthur Earland tells me that he knows it well as occurring in marine dredgings off British coasts.

Various other fossil fragments are often found in the residue obtained by washing clays, generally of the fresher water type. These include portions of insects; *Pisidium*, and fragments of the shells of other non-marine mollusca; and the seeds of plants as *Chara*, and others not identified.

Occasionally samples of the clays yield some quantity of red-burnt clay particles, which are attributed to fires, indicating ancient human occupation sites nearby.

Finally, free sulphur is present in some of the peat beds, and in the fragments of vegetation washed from the clays. It may be extracted in some quantity by a solvent, as carbon tetrachloride. Its origin is perhaps to be sought in the reduction of sulphates by bacteria.

I have to thank Mr. A. G. Brighton and Mr. Arthur Earland for their helpful criticism of the manuscript of this note.

TABLE A.

THE RELATIVE TOLERANCE OF BRACKISH WATER OF THE COMMONER FORAMINIFERA IN THE FENLAND DEPOSITS.

GROUP II.

Species recorded from the silt but not from the clay; relatively intolerant.

Textularia gramen d'Orbigny.
Cassidulina crassa d'Orbigny.
Lagena perlucida (Montagu).
L. reticulata (Macgillivray).
Marginulina glabra d'Orbigny.
Discorbis mediterranensis (d'Orbigny).
D. praegeri (Heron-Allen and Earland).
Lamarckina haliotidea (Heron-Allen and Earland).
Nonion pauperatus (Balkwill and Wright) (rare).

GROUP III.

Species occuring in 3–9 per cent of the clay samples; slightly tolerant; or intolerant, introduced with silt contamination.

Quinqueloculina subrotunda (Montagu).
Cornuspira involvens (Reuss).
Bulimina affinis d'Orbigny.
B. marginata d'Orbigny.
B. pupoides d'Orbigny.
Bolivina striatula[1] Cushman.
Lagena globosa (Montagu).
L. laevis (Montagu).
L. lineata (Williamson).
L. marginata (Walker and Boys).
L. scalariformis (Williamson).
L. semistriata Williamson.
L. substriata (Williamson).
L. williamsoni (Alcock).
Dentalina communis d'Orbigny.
Guttulina lactea (Walker and Jacob).
Sigmomorphina williamsoni (Terquem).
Uvigerina angulosa Williamson.
Globigerina bulloides d'Orbigny.
Discorbis williamsoni[2] Chapman and Parr.
Cibicides lobatulus (Walker and Jacob).
Planorbulina mediterranensis d'Orbigny.
Elphidium macellum (Fichtel and Moll).
E. oceanense (d'Orbigny).

GROUP IV.

Species occurring in 12–18 per cent of the clay samples.

Quinqueloculina fusca Brady.
Triloculina oblonga (Montagu).
Trochammina ochracea (Williamson).
Bolivina variabilis (Williamson).
Lagena clavata (d'Orbigny).
Discorbis globularis (d'Orbigny).
Elphidium icenorum Macfadyen MS.
E. incertum var. *clavata* (?) Cushman.

GROUP V.

Species occurring in 21–35 per cent of the clay samples.

Trochammina squamata Jones and Parker.
Buliminella elegantissima (d'Orbigny).
Virgulina fusiformis (Williamson).
Bolivina pseudoplicata Heron-Allen and Earland.
Lagena lucida (Williamson).
L. sulcata (Walker and Jacob).
Discorbis obtusus (d'Orbigny).

GROUP VI.

Species occurring in 43–53 per cent of the clay samples.

Trochammina inflata (Montagu).
T. macrescens Brady.
Elphidium excavatum (Terquem).
E. incertum (Williamson).

GROUP VII.

Species occurring in 75 per cent of the clay samples.

Rotalia beccarii (Linné).
Nonion depressulus (Walker and Jacob).

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[1] Hitherto recorded by the writer as *Bolivina* cf. *nobilis* Hantken.

[2] Hitherto recorded as *Discorbis nitidus* (Williamson) and recently renamed owing to preoccupation of the specific name.

TABLE B.

COMPARISON OF THE RELATIVE TOLERANCE OF BRACKISH WATER OF DIFFERENT SPECIES OF FENLAND FORAMINIFERA OF THE SAME GENUS.

Genus	Group II (Estuarine)	Group III	Group IV	Group V	Group VI	Group VII (Nearly fresh water)
Quinqueloculina	—	*subrotunda*	*fusca*	—	—	—
Trochammina	—	—	*ochracea*	*squamata*	*inflata* *macrescens*	—
Bolivina	—	*striatula*	*variabilis*	*pseudoplicata*	—	—
Lagena	*perlucida* *reticulata*	*globosa* *laevis* *lineata* *marginata* *scalariformis* *semistriata* *substriata* *williamsoni*	*clavata*	*lucida* *sulcata*	—	—
Discorbis	*praegeri* *mediterranensis*	*williamsoni*	*globularis*	*obtusus*	—	—
Nonion	*pauperatus*	—	—	—	—	*depressulus*
Elphidium	—	*macellum* *oceanense*	*icenorum* *incertum* var. *clavata* (?)	—	*excavatum* *incertum*	—

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The Grain-size Factor in Classification of Igneous Rocks.

By A. Kingsley Wells, King's College, London.

ALTHOUGH two years have passed since the British Association Committee on Rock Nomenclature and Classification reported in favour of using grain-size as an important factor in classification, very few petrologists have accepted the Committee's invitation to discuss and criticize the suggested scheme.[1] This silence may be taken to mean consent; but in some quarters the older scheme, based on mode of occurrence of the rocks, still finds favour. It is instructive to inquire how far it is correct to speak of the scheme as new. Actually one does not have to dig deeply into petrological literature to realize that the principle of grain-size classification has been advocated for many years; indeed, it was the guiding principle in some of the earliest scientific attempts at rock classification, notably in the well-known scheme elaborated in his *Lehrbuch der Petrographie* by Ferdinand Zirkel in 1866 and 1893–4. The reaction against the complete subordination of mode of occurrence found expression in the second edition of Rosenbusch's *Mikroskopische Physiographie* (1887), in which the igneous rocks were divided into (1) deep-seated rocks, (2) dyke rocks, and (3) effusive rocks, each of these main categories being subdivided in terms of mineral content. In quite recent times A. Johannsen (1931)[2] has followed the Rosenbusch tradition in making the primary division into (1) Deep-seated, Plutonites; (2) Hypabyssal rocks; (3) Extrusives, Vulcanites. A recent census taken by the Committee referred to above suggests an almost equal division of opinion concerning these two rival schemes.

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[1] Geol. Mag., LXXVIII, 1936, 319.

[2] *Descriptive Petrology of the Igneous Rocks*, i, 1931 (Chicago).

Right at the root of the disagreement lies the question as to whether it is preferable to classify rocks according to their visible and measurable characters; or to depend primarily upon the size and form of the rock-body of which the specimens under examination are small portions. It cannot be too strongly urged that the objects we are attempting to classify are small pieces of rock, normally some 5 × 4 × 1 inch in size. These natural objects are aggregates of crystals and mineral grains, and they vary in three ways, and in three ways only: in chemical composition, in mineral content and in texture, that is, in the size and arrangement of the component minerals. The first two of these factors are, to a very large extent, mutually interdependent: the mineral content of a rock is an expression of its chemical composition; but whereas the accurate determination of the latter is a lengthy and costly business, involving the services of a skilled analytical chemist, the former can be readily determined, in coarse-grained rocks by eye examination alone, supplemented by the microscope in those of finer grain. Consequently there is a wide measure of agreement in regarding mineral composition as fundamental in rock-classification. The difficulty arises over the choice of the second factor. True, the writer and many others would claim that there is no choice, for there is only one other variable factor—texture. Those who follow the Rosenbusch tradition, however, would disagree, particularly those who are uncompromising in their attitude and who base their nomenclature rigidly on mode of occurrence.

To make the matter clear it will be convenient to consider only the gabbroic rocks, which are alike in chemical and mineral composition, consisting essentially of clinopyroxene and plagioclase with or without olivine in addition. In a large collection of these rocks, classified rigidly according to mode of occurrence, all the specimens collected from lava flows fall in the category " Extrusive ", and would be labelled " Basalt "; all those occurring as sills and dykes are " Hypabyssal " and would be termed " Dolerite "[1]; while those from deep-seated, major intrusions are " Plutonic " and would be termed " Gabbro ". Many readers will doubtless recognize the following experience as their own, when studying such a rock collection classified on this basis. A student selects a specimen of black, compact rock, minutely crystalline, so much so in fact that the identification of the mineral grains as plagioclase and pyroxene is possible only with the microscope. It is labelled, "Basalt, lava flow, Mull." He picks up a second specimen, apparently identical, equally black, equally finely crystalline, composed of exactly the same minerals in the same proportions and of the same grain-size. Yet to his surprise, No. 2 is labelled, "Dolerite, sill, Arran." Rather puzzled the student picks up a third, very different-looking rock, much more coarsely crystalline, with its two components, glistening laths of plagioclase set in a matrix of dark green-black pyroxene, large enough to be seen with the naked eye. This, so different in appearance from No. 2 bears the same name as the latter: "Dolerite, sill, Dolgelley." The teacher, on being appealed to, would explain that these inconsistencies, so hopelessly puzzling to the student, result from basing the classification on geological occurrence: he has to admit that under this scheme there are no demonstrable differences between basalt and dolerite: he has to admit that Nos. 1 and 2, although bearing different names, are in fact, identical rocks; and that Nos. 2 and 3 are really different, although bearing the same label. Can it be wondered at that many students, who will ultimately hold important positions in the geological world, soon become resigned to the view that rock-naming is a mysterious, thoroughly illogical procedure to which the ordinary rules of nomenclature used by other scientists do not apply? They learn from experience that in petrology identical objects bear different names if they come from different occurrences; and that dissimilar objects may bear the same name. What would be thought of the botanist who applied two different names to the same plant, merely because it occurs in two different plant-assemblages; or of the zoologist who, possessing full knowledge of the structure of some well-known animal, confessed himself unable to classify or name it until he had been told where the creature lived? Happily an eel is still an eel, whether it is collected from the ocean floor, a mighty river, or an inland ditch; but a plagioclase-pyroxene rock of medium grain-size properly named dolerite if it occurs in a thin (hypabyssal) sheet of rock, becomes "gabbro" in a deep-seated mass, and "basalt" in a surface lava-flow.

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[1] Excluding the basaltic glass, Tachylyte (or tachylite), which even the most enthusiastic advocate of the scheme would hesitate to group as " Dolerite " though most of it is " Hypabyssal ".

Many petrologists (including the writer, by the way), brought up on the classification by mode of occurrence, have come to realize the disadvantages inherent in the scheme. Some have hesitated to disavow their old faith altogether, and have attempted to compromise; but compromise is impossible. The scheme is valid only in so far as rocks in the three main categories are mutually exclusive: "hypabyssal" rocks must be restricted to hypabyssal intrusions; the so-called "extrusives" to lava-flows. However, Johannsen (as did Rosenbusch before him) finds it necessary to include in the hypabyssal category, not only dykes and sills, but also small laccoliths in some cases, and border phases of major (plutonic) intrusions. In regard to the laccoliths, where is the line to be drawn between the hypabyssal laccoliths and the plutonic ones? Is it decided by size, or by depth below the surface? The writer has his suspicions that it is neither; but that by a curious inconsistency, the intrusion is judged by the rock it is built of: if the rock conforms to the petrologist's idea of "gabbro", the intrusion is dubbed "plutonic"; by definition, a rock of this composition and plutonic in habit is "gabbro"; this intrusion is plutonic, therefore the rock is "gabbro". On the other hand if the rock is of finer grain than typical gabbros, the intrusion is claimed as hypabyssal, and the term "dolerite" becomes applicable. Apart from this curious reasoning, however, it is most undesirable that in such cases nomenclature should be governed by the personal factor. Under this scheme gabbroic rock of laccolithic habit would be termed "gabbro" by the person who regards the intrusion as plutonic, but "dolerite" by another who thinks it is hypabyssal.

The position is weakened still further by the inclusion in the hypabyssal category of "border phases" of plutonic masses. An intrusion cannot be both plutonic and hypabyssal at the same time. How then can one intrusion yield rock-specimens with two different modes of occurrence? Obviously it does not: it yields specimens of both coarser and finer-grained rocks of the same composition—of "gabbro" and "dolerite" respectively. They are "gabbro" and "dolerite" not by reason of their mode of occurrence, but in virtue of their composition and grain-size. On what criterion have these writers found it necessary to widen the "hypabyssal" category so as to include border phases? Obviously on the criterion of texture. But the process of widening, with consequent overlapping, cannot be stopped at this point: it is a well-known fact that the thicker lava flows are as coarse internally as the rocks typically occurring as sills and dykes. Logically these also must be included in the "hypabyssal" category for exactly the same reason as applied in the case of the border phases. What then does "hypabyssal" really mean? The word has two quite different meanings. When applied to rock bodies it means "minor intrusions", such as sills, dykes, and veins; but when applied to a rock specimen it appears to mean a rock which forms part (not necessarily the whole) of a minor intrusion, or of a thick (extrusive) lava flow, or of the chilled phase of a major (plutonic) intrusion. Actually this does not tell us what a "hypabyssal" rock is, but merely how it occurs. Has the rock no individuality apart from its environment? Surely the individuality, or distinctiveness of a rock depends *wholly* upon its constituent minerals, their size and the manner of their arrangement; and although those who still pay lip-service to the classification by mode of occurrence would be unwilling to admit the fact, they do actually judge on texture, and not on field relations. Rosenbusch's three terms, appropriate to rock-bodies in virtue of their size, form and geological relations are not applicable to rock specimens. A little clear thinking on these lines is all that is required to clarify the existing confusion, which indeed should never have arisen: for J. P. Iddings (*Igneous Rocks*, i, 1909, 346) wrote that Rosenbusch, the originator of the scheme, " Intended to express a relationship between mode of occurrence and texture . . . but the method of treatment actually followed in the work was according to texture and not strictly according to geological occurrence."

The relationship that Rosenbusch wished to emphasize is a very significant fact in petrology; but it is of only general application. A close, unvarying relationship between mode of occurrence and texture is not to be expected, for the former is only one of several factors which control the latter.

In considering how far this relationship can be used as a basis of classification, two salient facts must be borne in mind. First, any rock series, the gabbroic rocks for example, comprising the range gabbro-dolerite-basalt, forms a series continuously variable in texture, especially in grain-size, ranging from the coarsest gabbro to the non-crystalline, glassy tachylyte. Secondly, this whole range of textural variation is covered by rocks having one mode of occurrence only. " Every known variation of texture from the most coarsely crystalline to the completely glassy is to be found among rocks that occur in the form of dykes " (Shand, *Eruptive Rocks*, 1927, 112). In illustration of this principle, the writer uses a hand-specimen, of normal size, of a beautiful little sill, complete with floor and roof, a little less than an inch in thickness, slightly transgressive to the bedding planes of the " killas " into which it was intruded. The intrusive rock is clearly granite, the quartz, alkali-felspar, and mica averaging $\frac{1}{16}$ in. or more in grain-diameter. This granite is demonstrably " hypabyssal " in mode of occurrence; but there is no reasonable alternative to the name " granite ", neither is there any reasonable objection to its use for this specimen. It is a small, perfect granite sill, though such a thing does not exist in the philosophy of the rigid supporter of classification by mode of occurrence; and though it would cause the compromiser still further to compromise his sense of logic.

It has been said that the study of rocks should start in the field, should continue in the laboratory, and should finish in the crucible. This sounds admirable, but is good advice only to the trained petrologist commencing work on some new area: it leads the tyro into all sorts of difficulties. The student has first to learn what " basalt ", " dolerite ", etc., look like, and how to distinguish them from one another. Then he should study the modes of occurrence of these rocks in the field. When this is done it creates no shock to discover tachylite dykes as well as tachylite lavas; he finds nothing abnormal in discovering that basalt dykes are as common as dolerite dykes; that trachyte occurs as flows, as plugs, as dykes, and as laccoliths; that identically similar mugearites form sills in Skye and lavas at Edinburgh. Why not, indeed. There is nothing unreasonable or unlikely in these discoveries. The broad principle which he applies is that all igneous rocks fall into one of the three following grain-size groups :—

A. Coarse grained, occurring normally, but not exclusively, in plutonic rock-bodies, belonging to the phase of major intrusions.
B. Medium grained, occurring normally as minor intrusions, belonging to the " dyke phase ".
C. Fine grained to glassy, occurring frequently as lava-flows, produced during the extrusive phase. Common also in minor intrusions.

In practice the mental process involved is as follows : a rock is found to consist of plagioclase and clinopyroxene, and therefore is gabbroic in composition. The grain-size exceeds the agreed limit[1] between dolerite and gabbro, therefore the rock is gabbro. The technique permits no equivocation, there are no " ifs " and " buts " involved ; only a simple measurement in border-line cases ; there are no unknown factors ; and the personal factor is eliminated. By this process all specimens of the same rock-type bear the same name, and one name only is applicable.

Were readers of these pages to ask themselves without bias to judge between the merits of the three schemes here discussed, and to act according to their judgment, the writer believes that many of our difficulties in petrographic nomenclature would soon disappear.

The Ifume Conglomerate, Tanganyika Territory.

By G. M. Stockley.

An interesting paper[2] has appeared in the *Bulletin* of the Royal Academy of Belgium, summarizing the general stratigraphy of the pre-Bukoban (i.e. pre-Devonian of Europe and pre-Katanga of Central Africa) rocks of Central Africa. It also includes a profile of the Basement Complex of Tanganyika. This note refers to the above-mentioned section of the paper only.

The writer has just investigated the area referred to, where a thick conglomerate is stated to occur within the rocks of the Lower Division of the Basement Complex, viz. :—

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[1] For the numerical limits between the grain-size groups, see the report in Geol. Mag., LXXVIII, 1936, 319.

[2] J. de la Vallée Poussin, " La Stratigraphie des terrains anciens dans la région des Grands Lacs Africains," *Bulletins de l'Académie royale de Belgique* (*Classe des Sciences*), no. 10, 1936, 1100–1110.

> "Au-dessus de cette première série on observe à l'Est de Karéma,[1] dans la vallée de l'Ifume, un poudingue épais (une centaine de mètres et peut-être sensiblement davantage) dont certains blocs dépassent le mètre cube. Parmi les cailloux roulés on reconnaît des gneiss œillés divers, des dolérites, des micaschistes, des quartzites, des granites anciens divers."

The presence of a conglomerate within the Lower Division of the Basement Complex is a fact of considerable importance in the stratigraphy of the ancient rocks of Tanganyika. Since no such observation had been made previously it was thought necessary to examine the relationship of this conglomerate in greater detail.

The writer cannot agree with M. Poussin that this conglomerate lies in the Lower Division of the Basement Complex. In his opinion it is a Karroo conglomerate faulted within the Complex. Such a phenomenon of blocks of Karroo rocks sunk within the older rocks is by no means uncommon in Tanganyika and, in the two coalfields (Namwele and Galula) situated on the edge of the Rukwa scarp, to the south-east of the area in question, this structure is found.

The following six reasons, based on field observations, convince the writer that the Ifume Conglomerate is of Karroo age :—

(1) No folding movement has affected these rocks in any way.

It is a commonplace that the rocks of the Basement Complex, more particularly also of the Lower Division, are always considerably folded.

(2) An unconformity was observed in the Ifume River, where the conglomerate overlies the Basement Complex.

The schists at this locality are dipping to the north-east, while the conglomerate and sandstones dip to the south-west. This south-westerly dip is constant throughout the whole outcrop. The rocks of the Basement Complex of this region although twisted and overturned in almost every direction have a general strike to the north-west.

(3) The included pebbles consist of representatives of all the rocks locally outcropping, namely the Basement Complex. The writer recognized among the pebbles the following: Pink crystalline limestone, white crystalline limestone, aplite, pegmatite, quartz, garnetiferous meta-dolerites, both acidic and basic granulites, hornblende- and biotite-gneisses, dense crushed rocks (mylonites) and epidiorites.

As the old shore-line existed nearby to the west and south-west of the conglomerate, most of the pebbles and boulders would naturally consist of representatives of the rocks occurring in those directions. M. Poussin admits the presence of dolerites among the pebbles of the conglomerate. Now dolerites are as yet unrecorded within the Basement Complex, but being post-Basement Complex in age they do suggest that this conglomerate is considerably younger. Those doleritic rocks of Basement Complex age are usually meta-dolerites (often garnetiferous, and generally placed in the Lower Division) and epidiorites. The latter are more common in the Upper Division.

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[1] Karema village is situated on the eastern shores of Lake Tanganyika, 140 miles south of Kigoma.

(4) The conglomerate is uncut by quartz veins, pegmatites, aplites, or dykes of any kind. Venation by quartz is known to occur in all pre-Karroo rocks. The Bukoban quartzites occurring at the south-eastern end of Lake Tanganyika and in the Uruwira area 70 miles to the north-east of Karema, are veined by quartz.

(5) The structure of the conglomerate.

The best sections are seen in the Ifume River, 3–5½ miles south-east of Sangu village, which in turn is situated about ten miles east of Karema Mission. The writer also observed numerous other small sections exposed in gullies and gutters in the area mapped.

The conglomerate outcrops for a distance of about twelve miles in a general north-west direction and has a width of approximately two and a half miles. Its main bulk is situated between the lower Ifume and Mtimba rivers. The faulted relationship was observed at (*a*) Situka (the north-west end), (*b*) in the Ifume River, and (*c*) along the southern boundary in a tributary of the Mtimba River.

Generally it is a boulder-conglomerate with a pinkish hue, and contains boulders often as large as 8½ feet in diameter with a large number 2–3 feet in diameter. A passage from coarser to finer types was commonly seen, while a deeper water facies was noted close to the Ifume River boundary, at three localities. At these localities red shales were found within the conglomerate overlain and underlain by sandstones. These unaltered argillaceous members occur as impersistent lenses, but their presence shows that they belong to an unmetamorphosed series.

One peculiarity of this conglomerate (and of all the conglomerates referred to latterly in this communication) is the presence of well-defined joints which cut across the pebbles and boulders, exposing their outlines in section. This fact suggests that the conglomerate cannot be ascribed to any group younger than Mesozoic, and thus the conglomerate may be referred to the Palaeozoic.

The western boundary (in and close to the Mtimba River) is covered by superficial deposits, but topographic features plus the constant dip to the south-west suggest that the conglomerate is faulted against the Basement Complex on that side.

(6) A Karroo age is further suggested by its lithological resemblance to other conglomerates occurring in the Rukwa trough, where Karroo rocks (containing seams of coal) are known to occur near the Mamba Mission (north-west of Lake Rukwa) in the Muse coalfield.

M. Poussin himself, in a written communication to the writer, expressed the view that the blocks of conglomerate in the Mongwe River[1] alluvium could not be distinguished from the Ifume conglomerate. The writer has examined the conglomerate exposed in the Mongwe River and finds a repetition of the Ifume conglomerate. The Mongwe conglomerate occurs beneath beds of arkose, sandstone, red and purple marls, and limestone which are identical with the Karroo rocks of the Muse coalfield.

The writer was able to show (*Short Paper No. 20*, Lands and Mines Dept., Dar es Salaam) that the conglomerates outcropping between the Ifume River and the northern end of the Rukwa trough are lithologically related. No fossils have, as yet, been found to prove conclusively their Karroo age, but on general grounds, as enumerated above, it seems to be a safe conclusion.

The Geology of the Fintry, Gargunnock, and Touch Hills.

By C. G. Dixon.

Introduction.

The area included in this survey comprises that part of the Clyde Plateau Lavas and associated sediments which lie within the Geological Survey 1 in. Sheet, number 39. This northern portion of the Campsie Fells was previously mapped for the Geological Survey by Peach and Jack, but the lavas were not separated into their petrographic types. It is this latter task that constitutes the main part of the work of this paper.

The plateau formed by these is highest in the north-west. The tops of the cliffs above Fintry are at an altitude of about 1,600 feet. The highest levels at Carleatheran, south-east of Kippen, are from 1,400–1,500 feet. This plateau slopes gradually eastwards until at the Touch Hills and to the south of these the general level is 700–800 feet. Most of the valleys run in east–west or north-west–south-east directions. Chief among these are the Endrick-Bannockburn valley and that occupied by the head waters of the Endrick.

The view of these hills from Stirling Castle is particularly striking. Their plateau nature is at once forced upon us. The great northern escarpment faces the Forth valley, and the slope is in two portions; a steep upper one marks the position of the lavas, and a lower and less steep slope is formed by the sediments that underlie them.

Another major escarpment occurs, its base being marked by the main tuff horizon. This cliff merges with the other as the tuff becomes thinner and thinner on being traced eastwards along the north face. The south side of the Fintry Hills is a very steep hillside which, curiously enough, has no apparent geological feature to explain it.

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[1] This river drains into the Rukwa trough to the north-west of Mamba Mission and south-east of Ifume River.

GEOLOGICAL FORMATIONS.

The geological formations represented in the area mapped are as follows :—

Clyde Plateau Lavas
Ballagan Sandstone
Ballagan Beds.

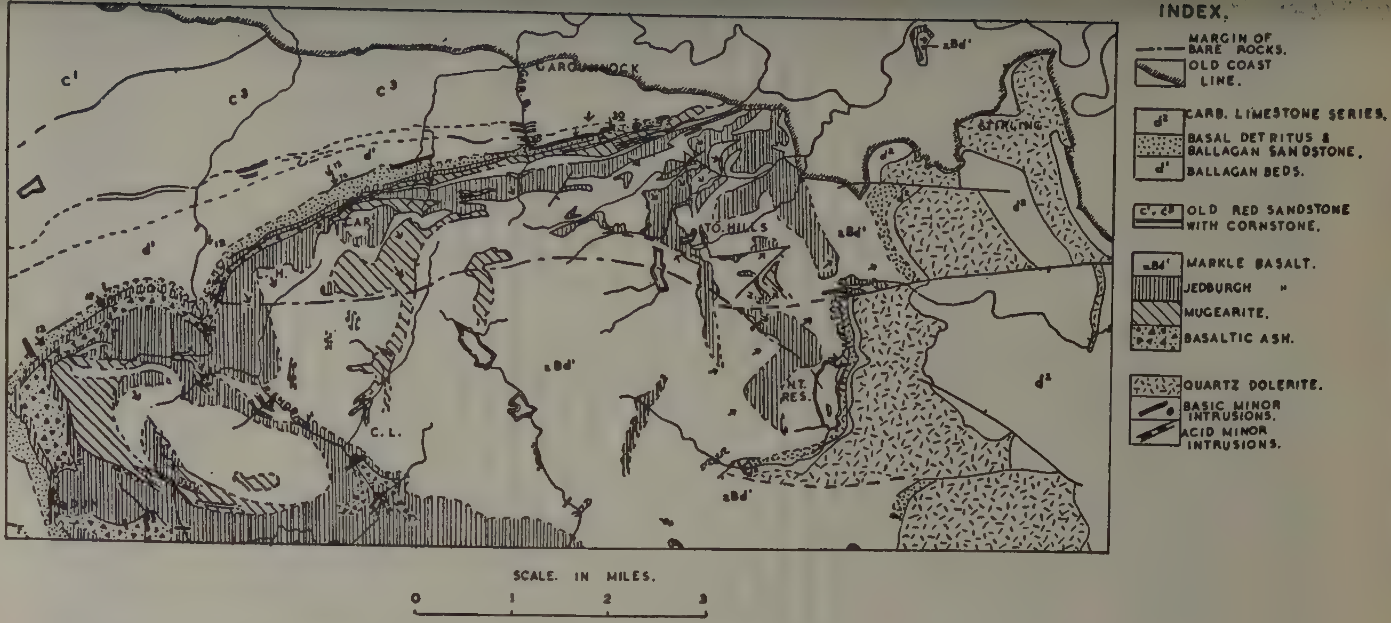
In the Ballagan Beds the sandstone bands are few and the cementstone bands are not so frequent as in the type section. At one point above Fintry the Ballagan Sandstone is coarse and pebbly, but otherwise there is no need for any amplification of what already appears in the relevant section of the Glasgow District Memoir. A very fine section of the Ballagan Beds is to be found in the Gargunnock Burn. Here the Cementstones are rather broken and disturbed.

STRUCTURAL RELATIONS.

A few words must be said with regard to the structural relations of the rocks of the neighbouring districts. The Campsie fault forms the southern boundary of the Campsie Fells and part of the northern boundary of the Kilpatrick Hills. The maximum throw is at the Garrell Burn, near Kilsyth (1), but it diminishes eastwards and westwards. This point is, of course, mentioned in the Glasgow District memoir, but it is nevertheless worth while drawing further attention to the subject here. A fault diminishes in the direction in which the rocks on each side, representing a given horizon, converge towards each other. The Kilpatrick Hills lavas dip in an easterly direction and are on the downthrow side, while the horizontal Campsie lavas are on the upthrow side. This means that we must travel west in order to find both at the same level. Similarly, eastwards from Kilsyth, the Campsie lavas dip towards the east, thus converging with the same horizon (not exposed, of course) south of the fault. The rocks with which this paper is concerned are a continuation of those of 1 in. Sheets 30 and 31 that have already received the attention of the Geological Survey. The boundary on the north is normal; the Cementstones giving place to the Old Red Sandstones in the usual manner. A little west of Stirling the lavas dip under the dolerite sill and its associated sediments.

It will no doubt be observed that the Cementstone Group is shown as though it thinned out altogether, with no attempt being made to explain this with the aid of a fault. The structural relations of the rocks of this neighbourhood are subject to discussion by Dinham (2) in the economic memoir for the Stirling and Clackmannan Coalfield. The opinion of Peach, the original investigator, was that by the time Causewayhead was reached the Cementstones and lavas ceased to be represented in the geological succession.

Dinham contests this view (3), stating that a strike fault would be a more likely explanation. Let us first of all recall the main points of



F. = FINTRY. CAR. = CARLEATHERAN. N.T. = NORTH THIRD. C.L. = CRINGATE LAW. L.H. = LEES HILL.

Geological Map of Fintry, Gargunnock, and Touch Hills.

his argument. He considers it unlikely that the rocks in question thin out quite so rapidly as was previously imagined, and draws attention to the lavas that outcrop in the Cleish Hills. The assumption that the Carboniferous Limestone rests on the Old Red Sandstone would, in his view, be very remarkable. The decrease in the thickness of the Cementstones is considered by him to be too great to be anything but a deception caused by a fault. It seems to the author of this paper that there is insufficient evidence to justify an abandonment of Peach's view. Is it not rather much to expect a fault to confine itself to such a narrow strip of sediments for such a distance? There is, in addition, no reason why the lavas and sediments should not cease to be represented. Precedent for this is to be found elsewhere. As an illustration of this last point let us refer to the geological memoir for North Ayrshire (4). In the neighbourhood of Saltcoats the lavas of the Renfrewshire Hills all but end, being represented by two flows, and the Cementstones are not represented at Kilbirnie, although they are found below the lavas in Sheet 30. The Cementstones, however, once more attain a considerable thickness south of the Inchgotrick fault, where they exceed 60 fathoms. In the economic memoir for Area IV of the Ayrshire Coalfield (5), a minimum of 60 to 70 fathoms of Cementstones has been proved. In this case there is no question of a strike fault being responsible. Dinham also speaks of the necessity for assuming that the Carboniferous Limestones would be resting directly on the Old Red Sandstone rocks, and that it would involve a more "marked unconformity than any known between the Fifeshire Lomonds and Lesmahagow". Such an unconformity does find parallel elsewhere. In the memoir for Area II (6) of the Ayrshire Coalfield we see the following: "...no representative of the group is present in the Burn Anne sections. . . . In these the Cementstone Group is also absent, and it is probable that beds of Carboniferous Limestone age rest directly on the Lower Old Red Sandstone". Geikie (7) says that south of the Pentlands the Carboniferous Limestone rests directly on the Lower Old Sandstone. A brief study of the north-east corner of the map will suffice to show that the entire succession of lavas can be seen within a very short distance. It is evident that they must have thinned out very greatly indeed. As Dinham's objections to Peach's view can satisfactorily be overcome, it seems to the author that there is no adequate reason why the Geological Survey should depart from their original opinion on the matter.

Volcanic Rocks.

General.—As has already been indicated, the main task was with the lavas. These are beautifully exposed in the northern part of the area, but are not so well exposed over the remainder. Nevertheless accurate mapping is quite possible. The individual bands are not very continuous, but they are sufficiently so to be well marked. At Kilsyth the Cementstones are interbedded with the lavas. This is not the case in the Fintry–Stirling district, where the normal Spout of Ballagan type of succession pertains.

Before going into details about the succession it would be advisable briefly to outline the grouping of the lavas to the south, as discussed in the Glasgow District memoir.

A more or less definite sequence holds throughout the greater part of this area. There is a lower group of microporphyritic lavas of Jedburgh type, and an upper group in which macroporphyritic lavas predominate, mostly Markle basalt, but mugearites are also abundantly represented. As the result of the great downthrow of the Campsie fault, the upper group also occurs in force in the Kilpatrick Hills. This grouping given in the memoir is stated to be of purely local value and is not strictly applicable in all parts of the map. For instance, it completely breaks down in the Garrel Hill region, just north of Kilsyth.

In the Fintry-Stirling area, the assemblage of lavas is extremely varied, not only in any single locality but from the place to place. It can be broadly stated that in the west there is a lower group of Jedburgh basalts which contains an important horizon of tuff, and an upper group very largely of Markle basalt but also having mugearites and Jedburgh flows. In the east, however, there is no such grouping; the volcanic pile being made up of lavas of Markle and Jedburgh types and very little mugearite. The above grouping into two main groups is, of course, an adoption of that indicated in the Glasgow District memoir.

At first glance it can be seen that all the exposed tuffs are in the western half of the area. As the vents, so far as it is known, are all to the west and south-west, something of this nature is perhaps what one might expect. Jedburgh lavas are much better developed in the Fintry Hills than elsewhere. They are invariably good Jedburghs, whereas in the Touch Hills they very often have affinities with the other types.

Fintry Hills.—The succession here commences with two or three flows of Jedburgh type. With these there is intercalated, a small flow of Markle basalt, just below Lees Hill. Next comes the main tuff bed. This is at its thickest in these parts and can be seen to splendid advantage in the burn section south of the Dun. On being traced northwards and eastwards it is found to become thinner and thinner until it ceases to be represented in the Gargunnock Hills. The lower group ends with several more Jedburgh flows. It is easy to see from the map that the upper group, if it may so be called, is a very heterogeneous one. For the most part this group is composed of mugearites and Markle flows, Jedburghs being subordinate. The Markle basalts are mostly higher than the mugearitic rocks, and are obviously part of the main body of Markle basalts that covers so large a part of the map. The mugearites, on the other hand, are a purely local feature and do not reach as far east as the Endrick Valley. In addition to the tuff mentioned above, there are few more. Two of them occur E.N.E. of the Dún, another two south of Cringate Law, and three small beds in the upper Endrick Valley west of Ling Hill.

Carleatheran and neighbourhood.—It is here that the two-fold grouping breaks down. The succession at Carleatheran itself still starts with a considerable number of Jedburgh flows. What might be called the lower group is made up as follows :—

8 flows of Jedburgh basalt.
1 flow of Markle basalt.
4 flows of mugearite.
1 flow of Jedburgh basalt.

The remainder of the succession in these parts is as follows :—

Several Markle basalt flows.
1 flow of mugearite.
2 flows of Markle basalt.
2 flows of mugearite.
2 flows of Markle basalt.
1 flow of mugearite.

The number of flows in the Markle band at the top cannot definitely be decided.

Gargunnock Burn.—In this section there is the exposure of Cementstones already mentioned.

Several flows of Markle basalt.
1 flow of mugearite.
6 flows of Markle basalt.
8 flows of Jedburgh basalt.
1 flow of mugearite.
5 flows of Markle basalt.
3 flows of mugearite.

The mugearite flow at the top of the above list is the same one as is mentioned in the Carleatheran section. It will be interesting to compare this section with the development of lavas seen at a point just before they dip beneath the overlying sediments at Touch. There must be some two dozen flows at the Gargunnock Burn section with the original number unknown.

Touch Hills.—A few words must now be said about the succession at the most easterly end. The flows are as follows :—

1 flow of Markle basalt.
1 flow of mugearite.
1 flow of Markle basalt.
2 flows of Jedburgh basalt.
1 flow of Markle basalt.
1 flow of Jedburgh basalt.
1 flow of Markle basalt.

The top of the uppermost band of Markle basalt is not seen in its entirety, but it is exposed below Murrayshall farm, about one mile farther south. Here there are five flows, so that the complete sequence at this end of the hills amounts to twelve flows.

Use has been made of a paper by Martin and Tyrrell in the *Transactions of the Glasgow Geological Society* (8). The specimens, which are in the keeping of Dr. Tyrrell, were examined afresh. The additional information thus supplied has proved to be of value in fixing boundaries.

INTRUSIONS.

Hitherto nothing has been said of the intrusive rocks. These are usually of the types that occur as lavas. The dolerite sill above Gargunnock is a basic rock with small phenocrysts of plagioclase and augite. East of the Dun, in the stream where the tuff is so beautifully exposed, there is a sill of orthoclase-porphyry and a dyke of the same material. The Dun itself is composed of fresh and fairly grained non-ophitic basalt. Close to it is an intrusion of mugearite which may or may not be a neck.

The trap featuring is so amazingly developed along the northern slopes of the hills as to be well worthy of comment. A line has been drawn on the map which divides the bare rocks from the less well exposed and somewhat peat- and drift-covered rocks south of the line. The reason for this must be that the ice from the north-west has stripped the ground of its covering with the result that we have a display of trap featuring that has to be seen to be appreciated. The ice flow must have been particularly rapid owing to the Stirling gap, and the cleaning up is of the type one commonly meets farther west, where there was a short run to the Atlantic, or at Edinburgh where the current was speeded up owing to the resistance of the Pentlands farther south.

ACKNOWLEDGMENT.

In conclusion the author wishes to acknowledge his indebtedness to his late professor, Dr. E. B. Bailey, for having spared neither time nor trouble in the supervision and guidance given throughout the research work and preparation of this paper. Thanks are also due o H.M. Geological Survey for permission to consult certain field maps. In the accompanying map, the old coast line and dolerite sills at Stirling are taken from Geological Survey maps.

REFERENCES.

1) "Geology of the Glasgow District," p. 166, *Mem. Geol. Surv.*
2) "Geology of the Stirling and Clackmannan Coalfield," *Mem. Geol. Surv.*
3) Ibid., p. 8.
4) "Geology of the N. Ayrshire Coalfield," p. 65, *Mem. Geol. Surv.*
5) "Geology of the Ayrshire Coalfield, Area IV," p. 21, *Mem. Geol. Surv.*

(6) "Geology of the Ayrshire Coalfield, Area II," p. 9, *Mem. Geol. Surv.*
(7) Geikie, *Ancient Volcanoes*, i, 361.
(8) *Trans. Glasgow Geol. Society*, xiii, 240. Martin and Tyrrell on a puddle trench section at North Third.

For a complete Bibliography see:—

MacGregor, A. G. *Trans. Glasgow Geol. Soc.*, xviii, pt. ii, 324.

The Geological Survey Regional Handbook, *The Geology of the Midland Valley of Scotland*, gives references to publications that have appeared since the date of the above paper.

CORRESPONDENCE.

SUBMARINE CANYONS.

Sir,—With reference to the article in your June number on the above subject, without wishing to belittle in any way a serious attempt to attack this problem, I think it should be pointed out that even if we concede (as the author seems to have proved) the possibility of submarine currents of some velocity, we have by no means surmounted all the difficulties.

The canyons in the American Continental Shelf are comparable in size with the Grand Canyon, for the erosion of which nearly the whole of the Tertiary seems to be demanded even using the two most powerful erosive agents, (*a*) alternations of heat and frost and (*b*) a ponderous armature to grind out the bed. If Daly's low sea-level ever occurred, its earliest date is Lower Pleistocene or, say, one sixth as much time as allowed for the erosion of the submarine canyons in the absence of (*a*) and, in place of (*b*) a presumably limited amount of broken material.

This second point has its importance, for the hypothesis would lead one to look for innumerable small canyons all along the Shelf instead of a few very large ones spaced at great distances.

Leaving aside submarine mountain masses, there are three classes of puzzling submarine features: canyons which align with great rivers, "deeps" which are fairly common in the neighbourhood of the British Isles and almost exclusively found in a narrow channel dividing two large bodies of water, and the canyons referred to above which plunge steeply through the edge of the Continental Shelf. Those who admit that the earth's crust can sink find no difficulty in accounting for the first class, explaining that the canyon was part of the river's valley when above water; they will also probably agree that where the "deeps" occur an isthmus once existed which was cut through when one body of water overflowed into the other at a lower level. As to the third class, in view of the small time allowance it seems likely that their formation was equally catastrophic.

R. G. Lewis.

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ORIGINAL ARTICLES.

On Brookite Crystals in the Dogger.

By R. H. Rastall.

IN the course of work in collaboration with Dr. J. E. Hemingway on the petrography of the Dogger of North-East Yorkshire it has been found that brookite is widely distributed as a "heavy mineral" constituent in several different kinds of sediment. This is in agreement with results obtained earlier by myself alone in the study of sandstones from higher horizons of the Middle Jurassic in Yorkshire.[1] Although it does not yet appear that the distribution of brookite in the Dogger is of any particular significance, nevertheless the mineral itself shows interesting peculiarities and variations; a detailed discussion of these would be out of all proportion in the paper which we hope to publish shortly on the character and distribution of the Dogger in general; and it has therefore been decided to give here a brief and mainly mineralogical account of the different varieties of brookite met with, without discussing the general problem of the abundance of titanium minerals in the Yorkshire Jurassics and their local distribution.

In the paper above quoted it was shown that in the sandstones brookite occurs in two distinct habits, and one of these was made the subject of a separate paper in the *Mineralogical Magazine* by Dr. F. Coles Phillips.[2] In the course of the present work, in addition to these, several other types have been discovered, which seem worthy of record.

In the Dogger the two types of brookite crystals already described are widely distributed, though it would be difficult to say which is the commoner. Frequently both are found in the same sample. The new types hereafter to be described are, so far as is known, more local. At a rough estimate brookite is present in about one-third of the total number of specimens examined, being common in the north and east, and in the central dales, but scarce in the south and west of the Yorkshire area.

It is easy to discriminate between the two common types. Both always occur as thin plates, which lie flat in the mount, and show the same general shape, although their crystallographic orientation is quite different. The standard type, as it may be called, is tabular parallel to 100, as in the textbooks: since the acute bisectrix is perpendicular to 100, the characteristic axial figure is seen in convergent light, with its intense dispersion and crossed axial planes. Another characteristic feature is that when a strong condenser is inserted below the stage with crossed nicols and parallel light, such plates do not give complete extinction in any position. Very commonly the crystal plates are of such a thickness as to give a red or violet interference colour in the 45° position, changing to a vivid yellowish green in the "straight" position, doubtless the complementary colour. This affords an easy means of picking out crystals of this habit and optical orientation. On the other hand crystals such as those described by Dr. Phillips, which are tabular parallel to 001, show no dispersion or axial figure in convergent light and extinguish sharply even with strongly convergent light. In these also hour-glass structure is common and characteristic. It will not be necessary to add anything to the very complete description of this type given by Dr. Phillips (see Text-fig. 1 *b*).

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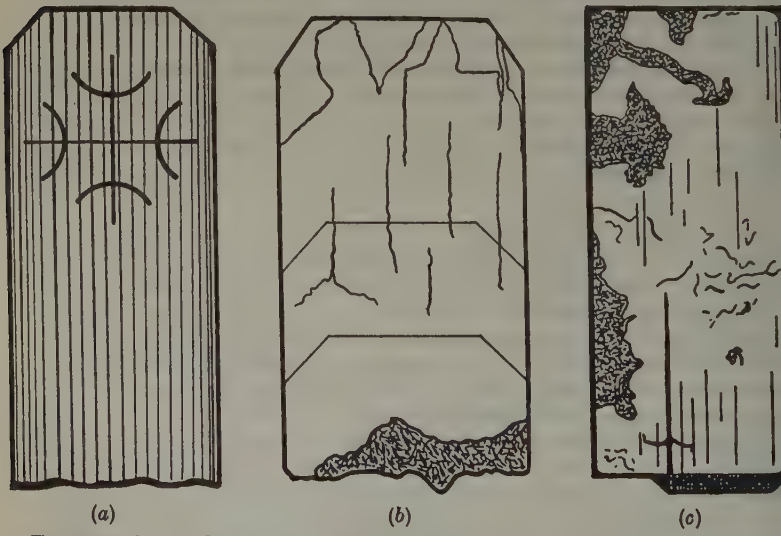
[1] *Proc. Yorks. Geol. Soc.*, xxii, 1932, 93.

[2] *Min. Mag.*, xxiii, 1932, 126; also Lindsey, *Min. Mag.*, xiv, 1905, 96.

The crystals of the standard (textbook) type are usually very thin flat plates parallel to 100, elongated along the crystal-axis Z, and nearly always distinctly striated parallel to this axis. They are rarely more than 0·1 mm. long and about a third as broad. They never seem to show double terminations. Some of them are simply rectangular in form, while others show corners modified by some 0*kl* form. The optic sign is always positive, the crystal-axis X corresponding to γ. Normally the optic axial planes are



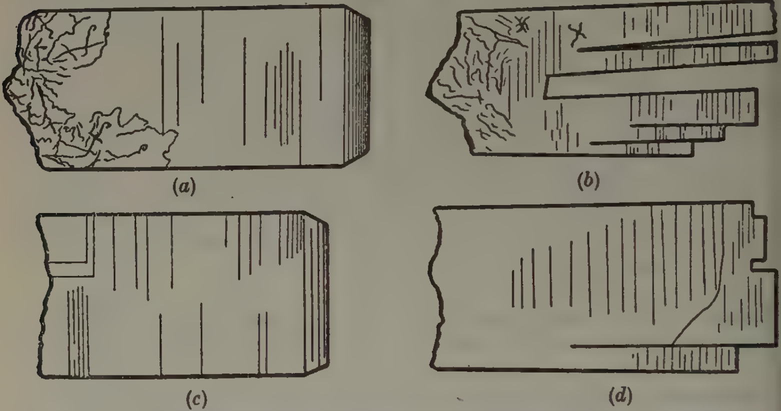
Text-fig. 1. (*a*) Diagram of brookite crystal of standard type tabular 100, elongation Z; O.A.P. red horizontal; O.A.P. blue vertical. (*b*) Crystal tabular 001, elongation Y (Phillips type). × 600. The hour-glass structure cannot be shown in a line drawing. (*c*) Large brookite crystal, Sandsend Road, orientation as in (*a*). × 180.

crossed, so that the axial figure in white light is peculiar and distinctive. Even in these tiny flakes a brilliant axial figure can be obtained by removing the Bertrand lens and the eyepiece. Since the O.A.P. for red is parallel to 001, the result is the production of two brilliant blue spots along the Y axis, the rest of the field being yellow and red. Usually the plates are sensibly uniaxial for Wratten light-filter ϵ or thereabouts, while with screens nearer the blue end of the spectrum the brushes open out notably in a plane at right angles to that for red. With a sodium arc lamp the brushes are well separated in the plane for red. These observations agree with the figures given by Iddings for 2E, namely, red $= 55°$, yellow $= 30°$, yellow-green $= 0°$, green $= 33°$, except that in most of the Dogger specimens the crossing point of the axial planes is distinctly nearer the blue end of the spectrum than is implied by these figures. On the average the crossing point of the optic axial planes is at about wave-length $5{\cdot}5 \times 10^{-5}$ cm., well in the middle of the green (Text-fig. 1 *a*).

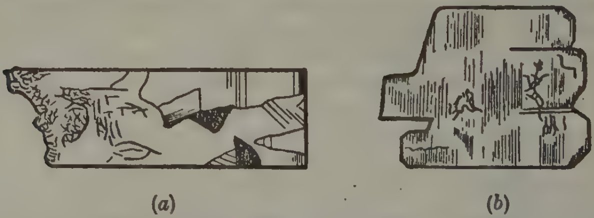
Most crystals, if not all, are definitely pleochroic, the absorption being slightly stronger for rays vibrating parallel to the Z crystal-axis: often pale orange, as against yellow for rays vibrating parallel to the Y axis. In such plates the third absorption colour for X obviously cannot be determined, as they invariably lie flat or nearly so in the mount, but Phillips has shown that $\gamma > \beta > \alpha$.

A short description will now be given of some brookite crystals from various Dogger localities differing from the commoner types either in crystal development (habit) or in optical properties. All of them are tabular parallel to 100, with the Bx*a* normal to this face. When Dr. Phillips wrote his paper on material from the sandstones it was not known that plates tabular parallel to 100 and elongated along the Y axis also exist. Many instances of this habit have been found in the Dogger, and a description will now be given of typical examples from Cat Beck, Kettleness (see Text-fig. 2 *b*). It should perhaps be noted that in the Dogger material the forms {021} and {110} figured by Phillips are as a rule very small or entirely absent, most crystal plates being almost simple rectangles or with only the minutest modification of the corners. This is notably the case in the type now to be described, in which the ends of the prisms are rectangular. Another peculiarity of development commonly shown in them is that each unit consists of several individuals of unequal length, either exactly parallel or with very slight divergence, as in Text-figs. 2 *b* and 3 *b*. The striations parallel to the Z axis, which are now across the prisms, are as a rule strongly marked, and the colour is often darker than usual, sometimes almost crimson with only a slight yellowish tinge. This type of elongation along the Y axis, in both simple prisms and multiple groups, is fairly common in a good many localities. At Beckhole, Goathland, where brookite is unusually abundant, a few crystals of this type are associated with a great preponderance of plates of the Phillips type. The optical characters are exactly the same as in the plates elongated along the Z axis: of course, the line joining the blue spots lies along the length of the prism, so that they are easily discriminated in convergent light (Text-fig. 3 *b*).

Text-fig 2 *c* is a somewhat generalized sketch of a type of crystal common in a concentrate from the main Dogger in a quarry close to the road at Knott Side, Rosedale. At this locality brookite is very abundant in thin flat plates, very simple in form and usually about 0·1 mm. long. They are of an unusually pale clear yellow colour with distinct pleochrism (stronger absorption parallel to striae). The elongation is Y and the optic picture very brilliant, probably owing to the pale colour and absence of inclusions. The axial planes are crossed, and the figure is definitely uniaxial for Wratten filter ϵ, showing a symmetrical black cross.



Text-fig. 2. Four examples of brookite crystals tabular 100, Y elongation. (*a*) West Gill, Northdale, Rosedale, (*b*) Cat Beck, Kettleness, (*c*) Knott Side, Rosedale, (*d*) Beckhole, Goathland. All × 400 approx.



Text-fig. 3. Brookite crystals with Y elongation. (*a*) Slidney Piece, Great Fryup, (*b*) Beckhole, Goathland.

In a concentrate from a siderite rock in the western gill at the head of Northdale, a branch of Rosedale, are several brookite crystals of a peculiar brownish-yellow colour with a tinge of pink. They are from 0·15 to 0·20 mm. long and of very simple form (Text-fig. 2 *a*). The elongation is Y and the cross striations are fairly well marked. The axial planes are crossed, red parallel to 001, but the dispersion is slightly different, the uniaxial wave-length being much nearer the red than usual, at about Wratten filter δ: with filter ϵ there is clear separation of the brushes in the plane for blue. This is probably to be correlated with the uncommon pinkish tinge in the colour of the crystals in ordinary light.

In an extremely interesting concentrate from a slightly oolitic sandy rock at Slidney Piece, Great Fryup, are found several different types of brookite: thus

(1) Broken and battered crystals with no dispersion and well-marked hour-glass structure.

(2) Flat plates in parallel groups with Y elongation, dark and speckly, with crossed axial planes.[1]

(3) Very thin flat plates of simple form, perfectly sharp and unworn, of a pale slightly pinkish yellow, with Y elongation, giving a most brilliant axial figure, so bright and clear that it is possible to see the dark brushes with filters much nearer the blue end than usual. 2E for blue is certainly as wide as 2E for red, and the figure is very nearly uniaxial for Wratten filter δ. One crystal (Text-fig. 3 *a*) with oblique striations in one segment gives a suggestion of twinning, the only such indication yet seen, and this is partly confirmed by the distribution of interference tints, but no twin law seems to be recorded for brookite.

The largest and most striking crystals of brookite yet seen were obtained from the Dogger of the Sandsend road section, about 2 miles west of Whitby. For some reason all the heavy mineral grains here are considerably larger than usual, and the brookites are on the average three times as large as any others, some reaching a length of 0·30 mm. The colour also is unusually vivid, deep orange or even crimson, or streaked and mottled with orange and crimson: dark inclusions are abundant. The elongation is Z; tabular parallel to 100; terminations rectangular or with small 0*kl* faces. The optical properties are, however, with one exception quite normal: Bx*a* $\perp$ 100; O.A.P. for red $\parallel$ 001; axial planes crossed. The figure is very nearly uniaxial for sodium light, a considerably longer wave-length than has been observed in any other instance: probably at about $5{\cdot}75 \times 10^{-5}$ cm. The usual ϵ filter shows quite a wide separation of the axial brushes in the 010 plane. This means that the crystals are uniaxial for yellow, not for green as usual (Text-fig. 1 *c*).

We now come to a type of crystal of rare occurrence in which the optical properties are quite different, in that the optic axes for all wave-lengths lie in the same plane, and the dispersion, still $\rho > v$, is quite small. The brushes therefore for light-filters of all colours look much the same. It is curious that no instances of intermediate forms have been found. Either the axial planes are completely crossed, with much the same values of 2V for red and for blue, or the dispersion is quite small. Nothing approaching a uniaxial figure for white light has ever been seen.

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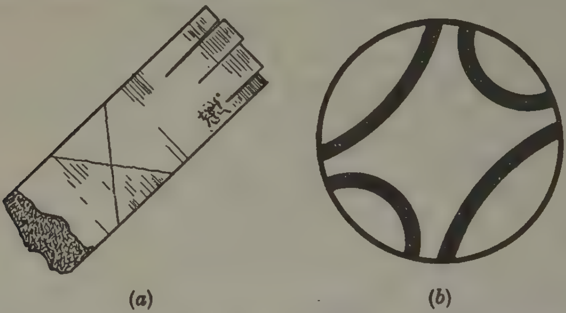
[1] The dark and speckled type of crystal here mentioned, which is common in more than one habit, is not shown in any of the accompanying figures, for obvious reasons. Some are almost opaque.

In the first place it should be mentioned that Dr. Phillips found that in the crystals described by him the axial planes were not crossed. In the Dogger material this point was first noticed in some very small simple plates from Beckhole, with Y elongation, tabular || 100, associated with a great predominance of 001 plates. These crystals are strongly striated across their length, so that there is no doubt of their orientation. The general colour is dark, almost crimson even in these tiny crystals, and the pleochroism is normal: (stronger absorption for rays vibrating parallel to striae). The acute bisectrix is normal to 100, as usual, but the axial plane for *all* wave-lengths is parallel to 001, with very small dispersion $\rho > \upsilon$. Consequently the axial figure for all colours is as shown diagrammatically in Text-fig. 4 *b*, which is drawn from the figure in sodium light. From this figure it may be inferred that the birefringence ($\beta - \alpha$) is stronger than usual, since in normal cases the first dark ring is outside the field of view of the microscope used, and only the axial brushes (isogyres) can be seen.



Text-fig. 4. (*a*) Brookite crystal from Beckhole with Y elongation. × 400. (*b*) Optic axial figure of the crystal for Na light in the same orientation.

In some very minute orange-coloured crystals of simple form from Black Beck, Baysdale, the axial planes are not crossed and the dispersion $\rho > \upsilon$ is very small. 2E for red appears to be rather larger than usual.

In this investigation nothing has been seen like the strange axial figures given by the brookite crystals from Tremadoc, or those figured by Brammall from Dartmoor.[1]

In addition to the remarkable dispersion the optical characters of brookite show some other points of interest. The refractive indices as usually given are $\alpha = 2{\cdot}583$, $\beta = 2{\cdot}586$ and $\gamma = 2{\cdot}741$, for sodium light. These may for all practical purposes be taken as the indices for white light. These figures show that the birefringence for pinakoidal plates, such as have been described in this paper, must show much variation. For 001 plates the birefringence is a maximum $(\gamma-\alpha) = 0{\cdot}158$. Therefore even the thinnest plates of this, the Phillips-Lindsey type, show interference colours of high orders. On the other hand the textbook type of 100 plates have a birefringence $(\beta-\alpha)$ of only 0·003, which is extremely weak. This accounts for the fact already mentioned that with convergent light even the first dark ring is not usually visible in the axial figure. Further, owing to the strong dispersion it is very difficult to obtain compensation in such plates and to determine the order of the interference colour. The fairly strong absorption of most crystals also increases the difficulty, by masking the interference colour.

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[1] *Proc. Geol. Assoc.*, xxxix, 1928, 31.

Without entering into an elaborate discussion of the super-normal, abnormal or subnormal interference colours, as defined by Rosenbusch-Wülfing,[1] resulting from the strong dispersion, it may be noted that the birefringence varies much for light of different wave-lengths. Thus according to Zepharovich $(\gamma-\alpha)$ for Li is only 0·1036, or just about two-thirds of that for Na light. Detailed figures for shorter wave-lengths do not seem to be available.[2]

The existence of crystal plates flattened parallel to 010 has not yet been demonstrated and a little consideration shows that they would be very difficult to detect by any optical methods. In the first place the birefringence $(\gamma-\beta)$ would be 0·155, which for all practical purposes is identical with that for 001 plates. These tiny crystals cannot be isolated for accurate index determinations, and even if they could there is no range of liquids with indices of this order. Again in 010 plates the characteristic striations, if present, would be parallel to the thin edge of the plates, and would be impossible to detect, even with the rotating stage, by means of which Dr. Phillips was enabled to detect them *across* the thin edges of his 001 plates. The hour-glass structure, so common in 001 plates, cannot be considered a safe criterion, since traces of it have been seen even in the textbook type of crystal.

It is therefore unsafe to assume that 010 plates do not exist, and in fact it is even probable that they do, since in certain concentrates there are often two or more types of crystal that agree in showing high birefringence and no dispersion (sharp extinction) but nevertheless differ markedly in other characters, such as habit, colour, presence or absence of hour-glass structure and so on.

Hence it appears that of the six possible types of pinakoidal crystals, three only have been certainly identified, namely 100 with Y and Z elongations, and 001 with Y elongation. The first two are easily distinguished by the relation of their axial figures to the striations, while the third shows no axial figure.

It is neither desirable nor possible to discuss at present the source of the great abundance of titanium minerals in the Dogger and other

[1] *Mikroskopische Physiographie*, I, i, 1921, 135 and I, ii, 277.

[2] Zepharovich, *Zeits. f. Krist.*, viii, 1884, 577.

Jurassic rocks of North-East Yorkshire. Only one point will be mentioned briefly here, namely, the occurrence of several different types of brookite crystals in the same rock, which is one of the most noteworthy results of the present investigation. It is quite clear that some are authigenic : in numerous instances the crystals are so sharp and perfectly formed, and obviously so fragile, that they cannot have been subjected to any mechanical attrition, while in rare cases prisms and plates have been seen attached in bunches to a matrix (possibly leucoxene) from which they have probably crystallized. In other instances the crystals are so obviously broken and worn that they must have been derived from some other source. It might be objected that the broken forms are due to crushing during preparation of the material, but whenever possible the separation was done by acid treatment of large chips, without any crushing at all, and the appearance of the crystals in mounts prepared in this way is just the same. It is perhaps worth mentioning, though the significance is not clear, that brookite crystals in sediments are never really rounded, although they are not specially hard and possess very poor cleavages.

Hence it may safely be concluded that the great variety of types of brookite crystals in the Dogger is due partly to growth in place and partly to derivation from other sources. What these sources were still remains a mystery.

Finally, I desire to thank Mr. F. W. Lanham and Mr. K. O. Rickson, of the Department of Mineralogy and Petrology, Cambridge, for drawing the figures illustrating this paper.

Petrological Studies in the Harlech Grit Series of Merionethshire. II: The Petrography and Petrology of some of the Grits.

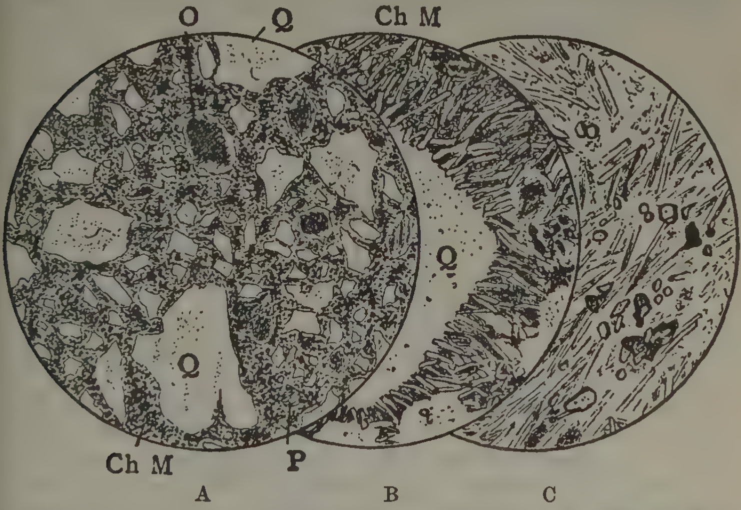
By Austin William Woodland, Department of Geology, Queen's University, Belfast.

I. Introduction.
II. Petrography of the Grits.
  (*a*) The coarser grained grits.
  (*b*) The fine-grained grits.
III. The Heavy Minerals of the Grits.
IV. General Petrology of the Grits.
V. Mode of Formation of the Grits and their Subsequent Alteration.
VI. List of Works to which Reference has been made.

I. Introduction.

THE grits which occur intercalated among the Harlech Grit Series have very similar lithological characters throughout. In the field the individual grits are very persistent laterally and can be traced over large areas. During the course of work on the manganiferous members of this Series one such grit horizon, which has been termed the " Bluestone Grit ", and which occurs about 5–6 ft.

above the manganese ore (i.e. about 36 ft. above the base of the Manganese Shale Group), was investigated in detail, largely because it was thought better to keep to one definite horizon when dealing with the variation in the "heavy mineral" content. Furthermore, the similarity of the grits throughout the whole succession together with their consistent lateral variations in grain size, etc., make a thorough examination of one such horizon virtually an examination of the grits of the whole series. The Petrography (II) is the result of an examination of sections from various horizons (largely within the Manganese Shales) and the "Heavy Minerals" (III) largely from the detailed examination of the Bluestone Grit.



TEXT-FIG. 1.—Grit; St. John's Church, Barmouth. A. General aspect showing angular fragments of quartz and felspar set in chloritic matrix; magnification × 20 diams. B. The fibres of chlorite and sericite are developed at right angles to the margins of the detrital grains; magnification × 100 diams. C. Small colourless and reddish-brown garnets occur within the chloritic matrix; magnification × 300 diams. Q—quartz; P—plagioclase; O—orthoclase; ChM—chloritic matrix.

II. THE PETROGRAPHY OF THE GRITS.

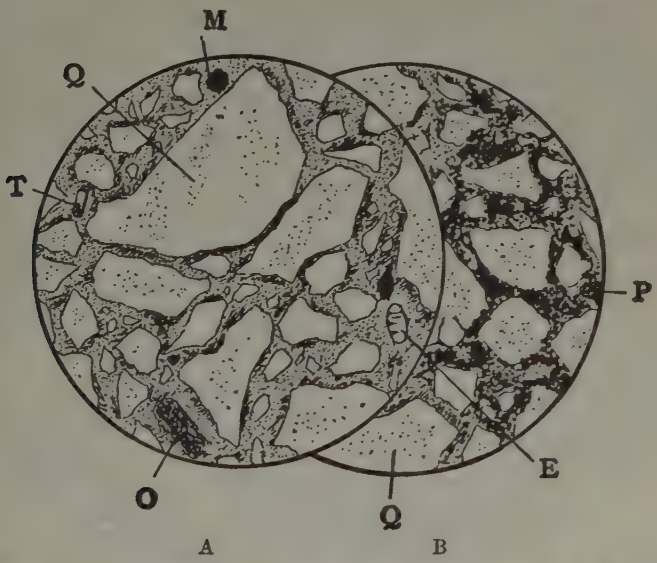
(*a*) *The coarser grained Grits.*—Macroscopic characters: the average grit is fairly coarse, greyish-green in colour, and fairly thickly bedded. The grain size varies considerably—it is most commonly about 1 mm., but rarer examples grade upwards into true conglomerates with quartz pebbles up to half an inch or more in diameter. Only the quartz is recognizable, this varying from colourless to a variety possessing a distinct purplish tinge. On weathering the surface takes on a bluish-black to deep brown colour, showing that small amounts of manganese are present in the matrix.

Microscopic characters: a typical grit consists of angular and subangular fragmental grains, consisting chiefly of quartz with very subordinate felspar, set irregularly in a matrix consisting chiefly of chlorite and sericite. Small spessartite garnets occurred scattered throughout the matrices of many of the grits from the lower portion of the Manganese Shales. The proportion of the larger scale fragmental material to the matrix varies somewhat, but is frequently about 1 : 1.

The fragmental grains have the following characters: *quartz* is practically all of the clear transparent type with very minute opaque and globular gas- or liquid-filled inclusions. Occasional grains show undulose extinction, but these in ordinary light are indistinguishable from the normal type. The *felspars* are subordinate, the predominant type being a very much decomposed orthoclase. Some fragments of decomposed material were originally plagioclase. Occasional small, remarkably fresh, lamellar twinned plagioclase felspars occur; these are mainly of one type, with an extinction of 10°–14° and are oligoclase. Among the rarer fragmental grains (usually much smaller in size) occur pale green, somewhat rounded *epidote*, *magnetite*, rare *muscovite*, and *zircon*. Although the felspars tend to show a more rounded outline than the quartz they are regarded as being of the same derivation; the decomposing felspars would be sufficiently softer than the quartz to yield more readily to the processes of rolling, etc.

The matrix consists of an intimate mixture of fibrous chlorite, fibrous sericite, and very minute quartz grains, and throughout this small colourless and reddish-brown garnets are frequently scattered. The chlorite and sericite occur usually in interlocking laths, although in places they may be more or less selectively developed in small patches. The chlorite is apparently all of the same variety: pale, though bright green in colour, with a distinct pleochroism. The sericite occurs as small colourless fibrous crystals, with a somewhat higher birefringence than the chlorite. There is a distinct tendency for the fibres to be oriented at right angles to the edges of the fragmental grains (Text-fig. 1B), while away from the margins of these grains the crystals are arranged quite haphazardly. The quartzose material is clear and free from inclusions. Sometimes it is localized into small clear patches, which in polarized light give a granular undulose extinction, not unlike that of chalcedony. The small colourless garnets vary somewhat in quantity in different grits, but they are often quite prominent, occurring scattered more or less uniformly throughout the whole matrix. They vary in size from 0·006 mm. to 0·025 mm., averaging 0·015 mm. to 0·018 mm. Many of the larger ones possess a good hexagonal outline, suggesting the rhombic dodecahedron. They have a high refractive index and stand out clearly. Small reddish-brown garnets usually accompany them; they are almost identical in every way but colour, and they often tend to occur concentrated in "nests". Owing to their small size, the behaviour of the garnets between crossed nicols is deceptive, but individuals isolated on the margins of the section are isotropic The amount of dialogite developed in the matrix varies considerably and it often appears to be totally absent.

On weathering the fragmental grains remain unchanged but the matrix shows chemical and mineralogical changes. The chief of these is the decarbonation of any dialogite that may be present, leaving in its place an opaque, black material, in granular masses (Text-fig. 2B); this is pyrolusite. The chlorite changes in colour from pale green to a golden yellow, finally becoming brown and yielding a finely disseminated blackish opaque material; these changes are therefore assumed to indicate the presence of a certain amount of manganese in the original chlorite.

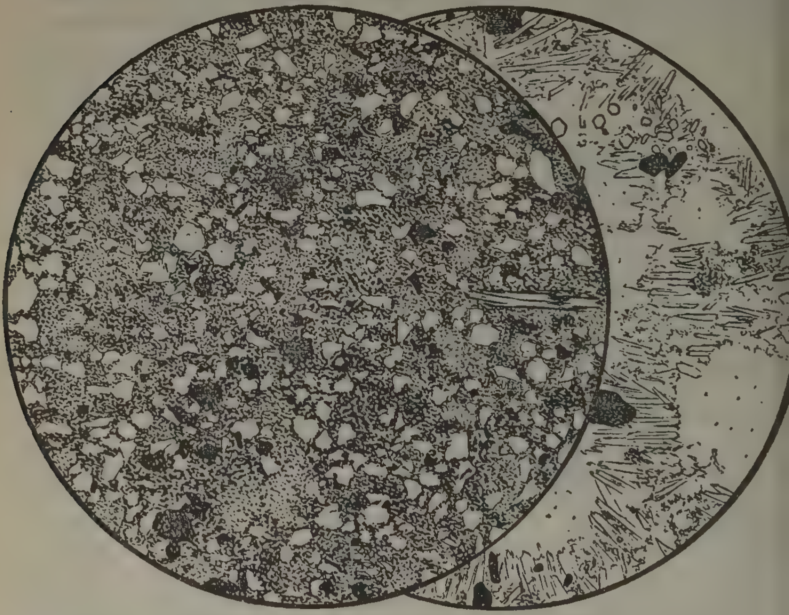


Text-fig. 2.—" Bluestone Grit"; East side of Llyn Dywarchen. A. General aspect of grit; angular quartz fragments (Q), subangular felspar (O), with occasional epidote (E), tourmaline (T), and magnetite (M) set in a fine-grained matrix of dialogite, chlorite, and silica. B. The same to show the mode of formation of pyrolusite (P) by decomposition of the carbonate on weathering; magnification × 30 diams.

(*b*) *The fine-grained Grits.*—Macroscopically these are fine-grained gritty rocks, often somewhat cleaved. Very small fragmental grains can be seen by the eye, and with the aid of a lens these can be seen to consist of quartz. The major portion of the rock consists of material of the silt grade.

Microscopically the rocks consist of angular and subangular fragments of quartz and felspar set in a matrix of much finer grade

(Text-fig. 3). The fragmental grains fall into two classes according to size. They are for the most part small, averaging 0·06 mm. to 0·12 mm. in size, but among these are scattered haphazardly fragments much larger in size, 0·3 mm. to 1·0 mm. The larger fragments are invariably of quartz; the smaller ones consist of 90–95 per cent of quartz, with the rest decomposing felspars or fresh oligoclase. The matrix which has recrystallized has eaten slightly into the surfaces of these grains and their outlines are not clearly marked.



Text-fig. 3.—" Bluestone Grit," Cil Cychwyn, Nantcol Valley. A. General aspect showing angular and subangular fragments of quartz and opaque minerals set in a much finer grained matrix, with rare flakes of white mica; magnification 40 diams. B. The matrix is a fine-grained intergrowth of lath-shaped chlorite crystals with silica, with interspersed minute euhedra of spessartite; magnification 350 diams.

Opaque minerals are occasionally abundant; these consist of magnetite (both authigenous and detrital) and pyrite (in euhedral cubes). The matrix is identical with that of the coarser grained grits.

III. The Heavy Minerals of the Grits.

Twenty-two grit samples in all were examined, including seventeen of the Bluestone Grit horizon. The usual procedure of heavy mineral separation was used: the rock sample was crushed, treated with warm dilute HCl, washed and the separation affected by bromoform (S.G. 2·91). With two samples the treatment with HCl was omitted.

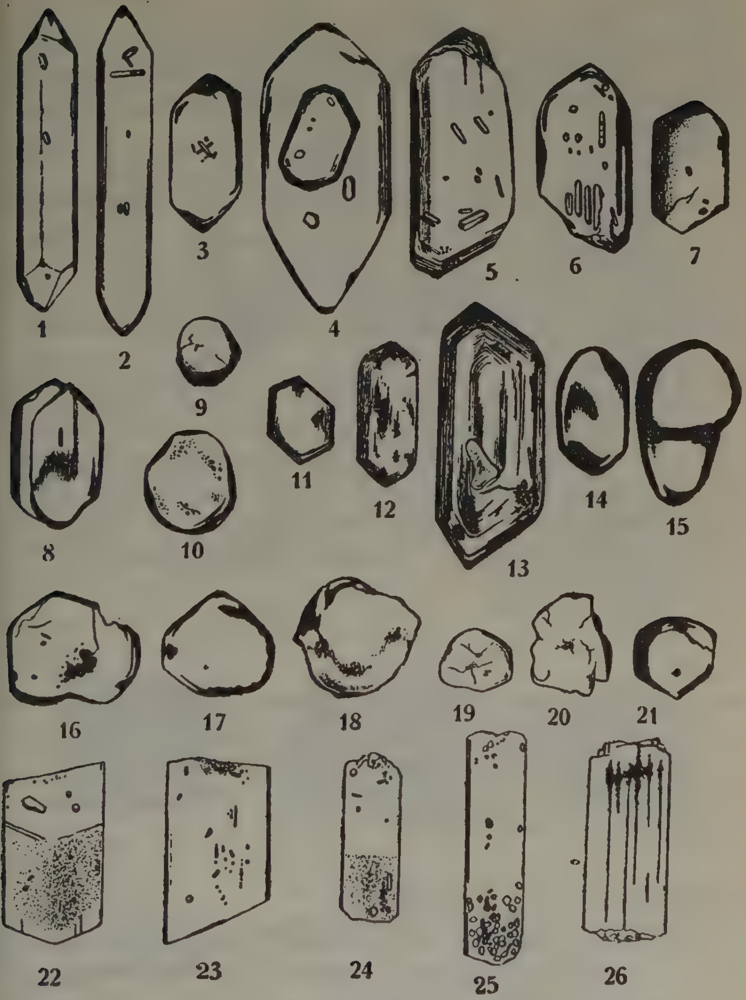
Throughout all the grits examined the heavy minerals were alike in their characters. The minerals recorded were: zircon, garnet, tourmaline, anatase, rutile, epidote, enstatite, diopside, biotite, sillimanite, apatite, ilmenite, haematite, magnetite, pyrite, chlorite, and in addition aggregate fragments containing numerous minute colourless garnets. Of these some of the magnetite, all the pyrite, the chlorite, and the garnet aggregates were authigenous.

Zircon.—This mineral occurs in all samples, and varies from 4 p.c. to 65 p.c. of the total allothigenous minerals, a good figure being 15–20 p.c. Three major types are distinguished: colourless, purple, and tawny. The colourless variety is the most abundant and it occurs in many forms. These can be conveniently divided into three groups: rounded, subangular, and euhedral. There is a general tendency for a decrease in size from euhedral through subangular to rounded forms. The euhedral forms are water clear, and show combinations of the tetragonal pyramid (110) with the tetragonal bipyramid (111), or with the ditetragonal bipyramid (311), or with both. They vary from stumpy, with length : breadth approximately 1 : 1, to elongate, with the same ratio up to 8 : 1. They occasionally show incipient zoning on the margins. Inclusions consist of zircons, apatite, gas-filled cavities, opaque materials, and clouds of indefinable opaque dust. The zircon inclusions are often euhedral. Frequently the inclusions are concentrated in the central region of the crystal. Some of the larger zircon inclusions themselves contain inclusions of a similar nature. In size the euhedral forms vary from 0·10 mm. to 0·20 mm., averaging 0·15 mm. The subangular types are similar to the euhedral forms except that they have lost their good shape; they vary in size from 0·07 mm. to 0·20 mm., averaging about 0·12 mm. The rounded forms are smaller and are often devoid of inclusions; 0·05 mm. to 0·15 mm., averaging 0·08 mm. The tawny forms average 2·5–3·5 p.c. of the allothigenous minerals. They occur in euhedral, subangular, and rounded forms. Euhedral forms often exhibit a good zoning parallel to the faces of the crystal. They have a range in size comparable with that of the colourless forms. The purple zircons vary somewhat in the intensity of their colour, but they are invariably very rounded and almost entirely free from inclusions; 0·08 mm. to 0·10 mm.

Garnet.—Varies in quantity up to 27 p.c. of the allothigenous minerals, forming on an average 5–10 p.c. Three types are distinguished: colourless, brown, and pink. Of these the colourless variety is by far the most abundant, and it is invariably present, while the brown variety, on the whole, is more frequent than the pink, though both are very sporadic. The grains tend to be more or less rounded but they are often irregularly fractured, and less commonly have six-sided outlines, somewhat modified by rolling. No perfectly euhedral grains occur. The colourless variety is frequently water-clear and free from inclusions, but the following inclusions might occur: opaque matter, zircon, rutile, and haematite. The brown variety frequently contains abundant inclusions, while the pink is nearly always free from them. All types have a similar grain size: 0·05 mm. to 0·12 mm., with an average of 0·08 mm. to 0·10 mm.

Tourmaline.—Is always present, though in varying quantities. It varies from 1·0 p.c. to 10·5 p.c. of the allothigenous minerals, averaging 3–4 p.c. The grains vary from being euhedral to subhedral, irregularly fractured, and, more rarely, quite rounded, in form. The euhedral crystals are prismatic with various basal terminations: (*a*) rhombohedral, (*b*) basal parting, (*c*) combination of *a* and *b*, (*d*) rare hemimorphic forms showing both *a* and *b*, (*e*) irregular parting devoid of all definite crystallographic direction, (*f*) irregularly fractured. The true rounded forms are not common, but they are of noteworthy occurrence in the Bluestone Grit of the S.W. slopes of Rhinog Fach. The brown variety is most common; this frequently grades into an olive-greenish brown variety, and one grain of a pale blue colour was recorded. The brown variety is intensely pleochroic from colourless or pale brown to deep or very deep brown; also from pale brown to deep greenish brown. Occasional crystals occur in which end portions are darker in colour than the rest of the crystal. The junction of two such portions is abrupt and may be a plane parallel to the basal termination; this indicates regeneration in crystallographic continuation with the original crystal. Prismatic crystals frequently show longitudinal striations. Inclusions are frequent: zircons (euhedral and anhedral), cavities, opaque particles, clouds of opaque dust, rutile, etc. Often the inclusions are confined to one end of a prismatic crystal. The distribution of these inclusions is limited on the inner sides by planes parallel to the basal terminations of the crystal, a feature again indicating re-growth in crystallographic continuation. The grains vary in size considerably, on the whole varying from 0·05 mm. to 0·20 mm., and averaging 0·10 mm. to 0·15 mm.

Anatase.—Is abundant only in one specimen (Bluestone Grit, near fishpond, Coed Lletty Walter), when it reaches 10·8 p.c. of the allothigenous minerals; on an average it forms less than 1 p.c. It occurs chiefly in irregular or tabular grains, sometimes deep blue in colour, but more frequently pale blue and non-pleochroic. They frequently show a distinct cleavage (001), while a tendency to fracture at right angles to this often gives rectangular step-like terminations to the grains. Generally the grains contain dense clouds of black inclusions (ilmenite ?). In some grains the inclusions are so dense that the grains themselves appear to be almost completely opaque. The inclusions are granular and devoid of all crystal shape. Only rarely are clear transparent grains observed. Some grains, the major portion of which contain numerous inclusions, show rectangular developments on the margins quite free from



TEXT-FIG. 4.

EXPLANATION OF TEXT-FIG. 4.

Magnification, × 200 diams. approx.

Zircons : 1–3.

1. Colourless euhedral form showing the face in relief.
2. Colourless euhedral elongate form with irregularly orientated inclusions of zircon.
3. Colourless euhedral form with euhedral inclusions of zircon concentrated in the central region.

Zircons: 4–15.

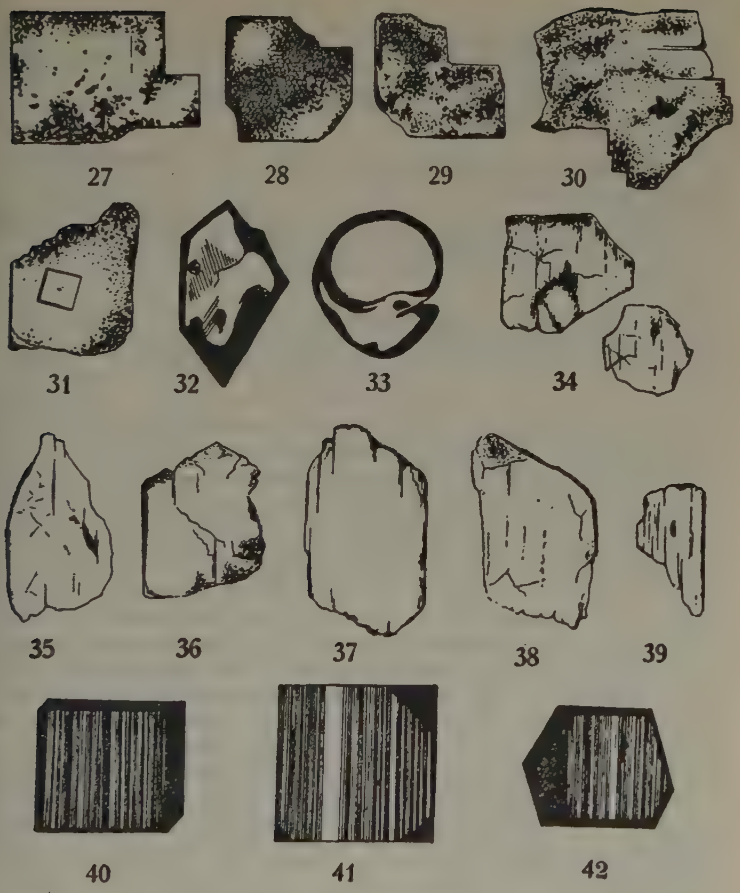
4. Colourless euhedral form with well-developed euhedral crystals of zircon. One inclusion is very large and shows a good prismatic form with bipyramidal terminations, with good zoning and inclusions of zircon.
5. Colourless, subhedral form showing ill-developed marginal zoning, with inclusions of zircon, some orientated parallel to the bipyramid terminations, and some haphazardly.
6. Colourless subhedral form with well-developed zircon inclusions orientated parallel to the major crystallographic axis of the crystal.
7. Colourless subhedral form with colourless zircon and opaque cloudy inclusions.
8. Colourless double form.
9. Colourless, rounded, with irregular cracks.
10. Colourless, rounded, with opaque and minute globular inclusions.
11. Tawny, euhedral, stumpy form with ill-developed zoning.
12. Tawny euhedral form showing good zoning and clouds of opaque dust inclusions in the central region.
13. Tawny euhedral form. A good prismatic crystal with (111) and (311) terminations. The zoning is due to the concentration of the colour in layers parallel to the margins of the crystal. Between these zones the crystal more or less approaches a colourless character. The zones are very numerous and narrow, and are more clearly marked when the crystal is orientated parallel to the direction of vibration of the lower nicol. The polarization colours are arranged in concentric layers, parallel to the edges of the crystal. Inclusions are: one cavity with irregularly rounded outline, presumably gas-filled; a few small stumpy crystals of zircon; and some clotted opaque material.
14. Purple rounded form.
15. Purple rounded form.

Garnets: 16–21.

16. Colourless subhedral form showing tendency to hexagonal outline with general rounding; inclusions of opaque material.
17. Colourless subhedral form with modified hexagonal outline on one side.
18. Colourless anhedral form showing pitted surface.
19. Colourless irregularly rounded with irregular cracks.
20. Colourless with irregularly fractured outline.
21. Colourless with hexagonal outline.

Tourmaline: 22–26.

22. Brown, prismatic form showing rhombohedral basal planes at one end. Inclusions of zircon and opaque particles. One end filled with clouds of opaque inclusions limited on inner side by planes parallel to the rhombohedral terminations.
23. Brown prismatic form with regular terminations devoid of crystallographic directions. Inclusions of rutile and zircon.
24. Brown, prismatic; basal terminations by basal parting and irregular fracture. Inclusions of opaque dust truncated on the inner side by plane parallel to the basal parting. Also inclusions of zircon.
25. Brown, prismatic form; one end crowded with quite large stumpy six-sided zircons and irregular rutiles.
26. Brown, prismatic; irregularly fractured terminations, longitudinal striations, and clotted opaque inclusions arranged in stringers parallel to the principal axis of the crystal.



Text-fig. 4 (*continued*).

Anatase: 27–31.

27. Pale blue, tabular; good outline and opaque inclusions more or less confined to the marginal regions.
28. Blue, tabular; good form and dense inclusions.
29. Pale blue, tabular; with dense inclusions; one corner broken away along (001) cleavage.
30. Pale blue, irregular, with good (001) cleavage and dense inclusions.
31. Pale blue, irregular grain relatively free from inclusions; bearing euhedral tabular grain on surface, quite free from inclusions and probably due to regeneration.

Rutile: 32–33.

32. Irregularly fractured grain of deep amber colour.
33. Well-rounded foxy-red form.

Epidote: 34–35.

34. Pale yellowish-green, irregular grain with fairly good cleavage.
35. Irregularly rounded, yellowish-green, with cleavage.

Epidote : 36–37.

36. Subangular, pale green; with decomposing margins bearing abundant inclusions.
37. Almost colourless, water clear, subhedral, with faint cleavage.

Enstatite : 38.

38. Colourless, prismatic, with ragged terminations and faint cleavage.

Sillimanite : 39.

39. Colourless, prismatic, with good cleavage and inclusion of zircon orientated parallel to the prism faces.

Pyrite : 40–42.

40. Euhedral, showing well-developed striations.
41. Euhedral, with well-developed striations and octahedron faces.
42. Euhedral, with good striations and pyritohedron faces.

inclusions; these suggest regeneration. In size the grains vary from 0·08 mm. to 0·40 mm., averaging 0·10 mm. to 0·15 mm.

Epidote.—Is one of the most characteristic heavy minerals of these rocks. It varies considerably in amount from less than 1 p.c. to 35 p.c. of the allothigenous minerals. It occurs in irregular and rounded grains, frequently possessing a good cleavage, with a small (4°–7°) extinction angle. It can be divided into three classes: (*a*) pale yellowish-green to nearly colourless, free from inclusions and usually possessing a good cleavage; (*b*) a deep green variety free from inclusions and usually devoid of cleavage; (*c*) a "dirty" green variety crowded with cloudy opaque inclusions and often much decomposed. The first variety is most abundant. All coloured forms are weakly pleochroic. They usually vary from 0·07 mm. to 0·15 mm., but rarely large platy grains, 0·25 mm. or more, occur.

Enstatite.—Is one of the rarer constituents. It occurs as colourless to yellow or brown, irregular and prismatic grains with faint cleavages and parallel extinction. It has a low birefringence which distinguishes it from epidote. The grains are from 0·06 mm. to 0·18 mm. in size.

Diopside.—This is very rare. It occurs in irregularly rounded or fractured prismatic grains with good, sometimes fibrous cleavage. Extinction is at an angle of 25°–30° with the cleavage traces. It varies from 0·12 mm. to 0·18 mm.

Biotite.—Also very rare, two grains only being recorded. One was a brown cleavage flake, decomposing marginally to green chlorite; the other showed the typical pleochroism and straight extinction. They measured 0·11 mm. and 0·14 mm.

Sillimanite.—Occurred in only two samples. Colourless prismatic grains with irregularly fractured basal terminations, a fairly well marked cleavage, parallel extinction, a positive biaxial figure, and a high birefringence. They vary from 0·07 mm. to 0·12 mm.

Apatite.—Owing to the treatment of the rock powders with HCl, this mineral was not recorded as a rule. In the two samples which were examined without treatment with HCl, it occurred rarely (six grains altogether). It can be concluded that it occurs throughout sporadically and in small amount. They occur as small (0·04–0·10 mm.), colourless, rounded or ovoid grains with low birefringence and straight extinction.

Ilmenite (*with leucoxene*).—It is only rarely as abundant as allothigenous magnetite in these rocks. It occurs as irregularly rounded and subangular grains varying in size from 0·06 mm. to 0·26 mm., and averaging 0·10 mm. to 0·15 mm. They are coated with the decomposition product leucoxene, this being the chief diagnostic character.

Haematite.—Is not common either as an allothigenous or as an authigenous constituent. Detrital fragments occur as irregular reddish-brown opaque masses 0·05 mm. to 0·12 mm. in size.

Magnetite.—Is by far the most abundant mineral in the residues. The two forms, allothigenous and authigenous, are both present almost invariably, although the relative amounts vary in the different samples. Irregularly rounded and anhedral fragments are distinguished as allothigenous, and the euhedral octahedra and freshly fractured grains as authigenous. Allothigenous magnetite varies from about 5 p.c. of the whole heavy residue to about 35 p.c. and the authigenous variety from 0–75 p.c. (Owing to the uncertainty of distinguishing accurately between the two varieties, the division is bound to be arbitrary; it must also be noted that this factor also affects the percentages of all the other allothigenous minerals, when represented as percentages of themselves.) The euhedra vary in size from 0·05 mm. to 0·35 mm. and the allothigenous forms from 0·05 mm. to 0·20 mm.

Pyrite.—Is invariably authigenous, and is almost always present, forming as much as 70 p.c. of the residue. On an average, however, percentages vary from 5 to 20. It occurs in good cubes, often with well developed striations parallel to the edges. Some of the crystals possess in addition to the cube faces, some of the faces of the pyritohedron, and very rarely octahedral faces are developed. Often the crystals possess a veneer of haematite. They vary in size from 0·06 mm. to 0·30 mm.

A marked tendency is observed for the authigenous magnetite and the pyrite to be present in inverse ratio to one another. That is, when authigenous magnetite is abundant, pyrite is relatively scarce and vice versa.

Chlorite.—Is almost always authigenous. Allothigenous chlorite is probably present in small quantities, but its determination under the circumstances is so difficult that it has not been distinguished.

IV. General Petrology of the Grits.

The abundance of the angular clear quartz fragments practically all of one type, the relative frequency of "kaolinized" orthoclase, and not infrequent oligoclase, indicates the derivation of these grits directly from a nearby ancient, somewhat "acid", gneissic landmass.

The general indications, as far as the Ardudwy tract is concerned, lead to the conclusion that this landmass lay to the east (Fearnsides, 1910, p. 792). The heavy minerals themselves shed little or no light upon the problem of their derivation. Among the transparent minerals, zircons are uniformly abundant and regularly distributed, but this is a characteristic of many sediments of all ages. Many are apparently of primary derivation, while there is an abundance of subangular and rounded forms, which indicates an origin in sediments. Purple zircons are characteristic and nearly always present, if in small quantity. W. Mackie (1923, p. 201) regards the Lewisian Gneiss of the North of Scotland as the source of all the purple zircons of the Scottish sediments, while A. Heard and R. Davies (1924, p. 509) assume that the purple zircons of the Old Red Sandstone of South Wales were directly derived from rocks similar to the Lewisian Gneiss. The purple zircons of these grits, however, are invariably thoroughly rounded [a condition also noted in the Bala and Valentian Series in Radnorshire and Carmarthenshire by J. I. Platt and K. A. Davies (1933, p. 213) ; by F. Smithson in the Cambrian rocks of Cos. Dublin and Wicklow (1928, p. 18) ; by S. A. Billinghurst in the Arenig rocks of Carnarvonshire (1929, p. 296), and others], which suggests that they are either not of primary origin or that they have travelled very great distances. The former is most likely since the source of these sediments is regarded as having been close at hand.

Among the garnets the colourless variety is most characteristic, a condition also true of the Cambrian rocks in the English Midlands (Fleet, 1925, p. 102), and the Ordovician rocks of Carnarvonshire (Billinghurst, 1929, p. 295).

Epidote varies somewhat in occurrence, but is on the whole very characteristic. It is not a commonly recorded mineral in heavy residues. Platt and Davies (1933, p. 214) record it sporadically in the Bala Grits of Mid Wales, and Smithson (1928, p. 20) records it in a sample of quartzite from Carrickgollogan. It is absent from the Cambrian rocks of the English Midlands. However, it fits in with an origin in a complex similar to that now exposed in the Mona Complex of Anglesey, where epidote abounds.

The presence of anatase is significant. It is invariably of the blue variety and always has a tabular form. It is interesting to note that while the blue variety is recorded from the Cambrian rocks of the English Midlands, the yellow variety also is common (Fleet, 1925, p. 98), while in the Dublin district the blue variety only is recorded from the Cambrian quartzite (Smithson, 1928, p. 12).

Thus examination of the heavy minerals of the grits leads to the conclusion that the landmass from which they were derived consisted of a complex of granitic gneisses (giving abundant quartz and some felspar), sedimentary rocks (giving the minerals of at least second derivation), metamorphic rocks (giving the garnet and epidote), and basic igneous rocks (giving epidote, enstatite and diopside). This would be a complex similar to the Pre-Cambrian of Anglesey.

V. MODE OF ORIGIN OF THE GRITS AND THEIR SUBSEQUENT ALTERATION.

The materials forming the grits fall into two classes—relatively coarse detrital fragments and very fine-grained uniform matrix material. In the coarser grits the detrital fragments form approximately one-half to two-thirds of the rock, while in the finer grained rocks the matrix material tends to predominate. That the two components were laid down contemporaneously is obvious from their closely intermixed relations ; it is also clear that they belong to two different phases. There was little or no separation of the two phases by the ordinary means of grading under gravity or by lateral transportation. If both the detrital fragments and the fine-grained material represented ordinary suspended material, settling under the laws of gravity, there would at least be present all grades of material from very fine to coarse, in a sediment containing both, and in addition there would be a tendency for the ordinary laws of grading to operate. Both these conditions tend to be absent. The coarser grained grits contain only coarse fragments and the exceedingly fine-grained matrix. If, then, the fine-grained matrix represents a phase different from that of the ordinary detrital materials, that phase being fine-grained, must be one of colloidal suspension. It is postulated therefore that the matrix of these grits represents a colloidal suspensate of clayey aluminous and siliceous materials, which were subjected to constant flocculation, so becoming a constant component of all the rocks of this group from fine-grained to coarse grits. Since it forms upward of 50 per cent of even the coarse grits it follows that accumulation of this material by flocculation must have been taking place very rapidly. Prof. Boswell (1930) has suggested that co-precipitation of these fine-grained colloidal materials takes place by the action of electro-positive colloids and that in an enclosed or partially enclosed basin, precipitation of fine-grained sediment may take place " at such a rate that even where the supply is not continuous and the depth of water not small the sediment remains undifferentiated into grades ". Whether or not such action was induced within these Cambrian sediments, as for example by the presence of colloidal manganese carbonate, flocculation of the fine-grained materials took place continuously and so they became intimately mixed with the coarse detrital material that was periodically laid down within the basin of deposition.

Low grade metamorphism, induced by induration at great depths, resulted in the recrystallization of the fine-grained matrix. Chlorite and sericite were formed from the aluminous materials and spessartite garnets were produced by the combination of manganese carbonate with aluminous material and silica. In fact the recrystallization of the aluminous matrix is identical with that displayed by the normal mudstones of the Manganese Shale group which has been described before.

VI. List of Works to which Reference is Made.

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A New Species of *Temnocheilus* McCoy from Holy Island, Northumberland.

By Margery I. Platt, Royal Scottish Museum, Edinburgh.

(PLATE XVI.)

THE fossil nautiloid here described was brought for identification to the Royal Scottish Museum, Edinburgh in 1935. It was obtained from the limestone on the southern shore of Holy Island, opposite the Priory, by Mr. G. J. Romanes, of Edinburgh, who has kindly presented it (Reg. No. 1937.78.1) and the associated fossils to the Museum, and given me permission to describe it. According to the most recent account of the Geology of Holy Island (*Mem. Geol. Surv.*, 1927) it is certain that the limestone from which the nautiloid was derived is the Acre Limestone. This is a characteristic limestone in the middle group of the Upper Bernician Series of Northumberland (Smith, 1910) and I am indebted to Mr. R. G. Carruthers of the Geological Survey for the additional information that this bed can now be definitely correlated with the Middle Skateraw Limestone exposed on the East Lothian coast at Dunbar. Up to date, however, no specimens of *Temnocheilus* have been recorded from the Scottish side.

TEMNOCHEILUS McCoy.

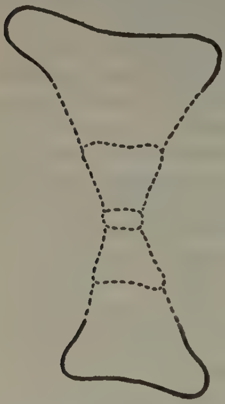
Temnocheilus ventro-concavus, sp. nov. (Pl. XVI, Figs. 1 and 2).

Generic Features of the Fossil.

There seems little doubt that this nautiloid belongs to the genus *Temnocheilus* originally described by McCoy (1862). The various parts of the broken fossil have been put together, and so assembled, the general outline and features of the conch are easily discernible. It is incomplete on the lateral areas, unfortunately, since the test and some of the underlying parts have been chiselled away accidentally during its extraction from the rock. In consequence, the inner whorls of the spiral are damaged or missing, and thus the extent and nature of the umbilicus cannot be estimated from either side. The appearance of the last chamber suggests that the nautiloid was involute, and this part in section is of quasi-quadrilateral shape. There is a departure from any exact symmetry owing to lateral distortion caused by cleavage. Actual measurements of the whorl section in the last chamber give a maximum width of 8 cm., and a depth of approximately 6 cm. (the last measurement cannot be exact because of the damage the fossil has sustained). This ratio, width/height, relating to the whorl section, is of significance to the genus *Temnocheilus*, for according to the American authors—Miller and Owen—(1934, p. 222) it should typically be an improper fraction. The dorso-ventral depression responsible for such a ratio is evidently a characteristic feature of *Temnocheilus*, and distinguishes it clearly from *Metacoceras* and *Domatoceras*, genera which are often confused with *Temnocheilus*. Other characters of the Holy Island specimen which are in agreement with those noted in the original description of *Temnocheilus* given by McCoy are: shell discoid, a deep sinus present in the middle of the venter ("outer lip"), and septa simple. One feature mentioned by McCoy —the siphuncle—is not evident in this specimen, and consequently its position in the whorl section is not known.

Description.

The conch of *Temnocheilus ventro-concavus* is a massive and heavy spiral, from general side view resembling a crown with an upper and lower scalloped edge provided by the outline of the ornamentation of tubercles on the ventro-lateral margins. It measures across the lateral area along its greatest diameter from the last chamber of the shell, 184 mm. The last whorl increases rapidly in size, and then diminishes again slightly as the last chamber is reached. Corresponding with this variation in size of the outer whorl, the venter increases in width from 46·2 mm. at the beginning to a maximum of 89·8 mm., while at the extreme adoral end it is only 81·2 mm. wide. All these data take into account the height of the ornamentation which affects both lateral and peripheral surfaces. The shell is discoid with its lateral surfaces converging dorsally, the sides of a perfect conch of this kind could therefore be shallow concavities with the umbilicus in the centre of each. The venter is flattened, the two sides extending inwards with a gentle slope forming a slight depression along the entire peripheral surface. The only ornamentation consists of a continuous series of tubercles, bluntly rounded and elliptical in section, the long axes being placed in line with the circumference of the shell. The tubercles surmount the angle formed by the junction of the ventral and lateral surfaces, and there are fifteen to the last whorl. Growth lines are indicated on those parts of the replaced test which still remain. They appear to be straight on the lateral sides, and are continued over the tubercles, on to the venter, where they sweep backwards away from the aperture of the shell, forming the hyponomic sinus characteristic of this genus and also found in so many other nautiloids. The hyponomic sinus in this fossil is most marked on the adoral portion of the venter. A few septa are exposed at one part of the broken conch. They are straight, quite devoid of any folding so far as it is possible to judge; in the last whorl near the periphery they are placed 11–12 mm. apart, two septal chambers corresponding roughly with one tubercle. It is impossible to state definitely whether the shell is involute, owing to the crushed and distorted condition of the conch, but its appearance suggests that it was. For the same reason an estimate of the number of whorls cannot be made. The accompanying diagram (Text-fig. 1) has been constructed from the conch, but the outline of the middle whorls is entirely assumed, and is indicated by a dotted line.


TEXT-FIG. 1.—Median section of *Temnocheilus ventro-concavus*, sp. nov., × ⅓ approx.

Affinities.

A comparison of figures and descriptions of already recorded species of *Temnocheilus* at first led me to consider that this Holy Island form might be a variety of McCoy's type, *T. coronatus*. An examination of the various representatives of this species in the Sedgwick Museum, Cambridge, and the British Museum (Natural History), London, has altered my opinion. Specimens of *T. coronatus* in this country all agree with McCoy's figured type in being of decidedly subglobose shape with a very rounded venter. The distribution of low tubercles ornamenting the ventro-lateral margins of the conch varies even among these recognized members of the same species. In specimens of similar small size, one from Lowick, Northumberland, has the tubercles most marked in the inner or adapical portion, whilst the other from Settle, Yorkshire, has the tubercles more distinct in the outer or adoral portion of the shell. In general, *T. ventro-concavus* does not resemble *T. coronatus* in shape. The difference is due to the markedly discoidal shape of the former, surmounted with an ornamentation of tubercles larger than those of any *T. coronatus* I have seen; but the greatest distinction lies in the flattened and uniformly shallow concavity of the venter of the Holy Island form. At the beginning of the present century a second and larger nautilus was found at Little Is., Cork, in the same quarry where the type *T. coronatus* had been obtained much earlier. This also was referred by Foord (1897–1903, p. 206) to *T. coronatus*, but it is discoid in shape, with a flattened though slightly convex venter. In my opinion this fossil is not typical of the species *T. coronatus*, and is in fact intermediate between the type which it is supposed to represent, and the discoid form from Holy Island which is now the subject of discussion.

Other nautiloids have points of resemblance with this new form, though with none can I associate it completely. A few from the Carboniferous Limestone of Central Russia, described and figured by Tzwetaev (1888), appear similar in some respects, the chief among these being *Nautilus dorso-armatus* Abich, the type of which was derived from the Caucasus and described by the author (Abich, 1875). Both these forms share with *T. ventro-concavus* its dominant and most unusual feature, a concave venter. They have also an ornamentation of tubercles, supplemented, however, by faint radial ribbing on the lateral areas, a character not present in the British fossil. The whorl sections of all these are very similar. The Eastern European fossils are very small compared with the Holy Island form, but this disparity in size may serve to indicate that had the smaller fossils attained a greater size, their resemblance with *T. ventro-concavus* might have been still more complete. Further the tubercles of the species, *N. dorso-armatus* are circular in section and distinct elements, whereas those of the Holy Island form are ellipsoid and continuous.

Reference must now be made to two American species of *Temnocheilus* which in many respects resemble our specimen. The first of these, *T. harneri* Miller and Owen, from the vicinity of the Tebo Coal, Henry County, Missouri, is like ours a heavy discoid nautiloid with a maximum diameter of 135 mm., being rather smaller than the Holy Island specimen which measures 184 mm. (Miller and Owen, p. 223). The tubercles of T. *harneri* are more circular, papillate, and in a discontinuous series, but like ours there are fifteen to the outer whorl. The venter is broadly rounded, with its medium third flattened or slightly concave and bordered by two faint ridges. A close relative of this species, *Temnocheilus latus* Meek and Worthen, in some features even more closely resembles our specimen than *T. harneri*. One fossil in the British Museum (Natural History) designated *T. latum* (c. 4486) from an unknown American locality almost equals ours in size, measuring 154 mm. along its greatest diameter. The tubercles bordering the ventro-lateral margins are, like ours, blunt and continuous in series, but although distinct on the inner whorls they become less prominent on the adoral portion of the conch. The other nautilus of this species described by Meek and Worthen (1870) from the Lower Pennsylvanian of Illinois is recorded as possessing sixteen nodes to the outer whorl compared with our fifteen. The venter of *T. latus* appears to be strictly similar to that of *T. harneri* and in this respect therefore deviates from our specimen.

As a result of this close comparison of allied species of the genus *Temnocheilus*, the combined features of this representative from Holy Island serve to dissociate it from any previously recorded specimen. The flattened concave character of the venter at once gives the fossil a signal appearance distinguishing it from closely related British forms, and in consequence I propose to give it new specific rank and designate it *T. ventro-concavus*.

Summary.

Although British and American forms of this genus all bear points of resemblance to *Temnocheilus ventro-concavus*, only two small specimens from Eastern Europe, *Nautilus dorso-armatus* Abich, resemble it in their possession of a flattened concave venter and a whorl section of quasi-quadrilateral shape.

Associated Fauna.

The Acre limestone is generally fossiliferous, and many small marine fossils were found in association with *Temnocheilus ventro-concavus*. There were several specimens of *Productus* (*Eomarginifera*) *setosus* Phillips; two corals, *Zaphrentis* cf. *delanouei* Edwards and Haime, and *Lithostrotion irregulare* Phillips; *Spirifer* sp. (near *bisulcata*): *Pleurotomaria* sp. preserved in galena; *Ctenodonta laevirostris* (Portlock); and numerous crinoid stems. Dr. Stanley Smith (1910) recorded a similar faunal assemblage for this limestone some years ago.

In conclusion I wish to record my gratitude to Mr. F. W. Anderson, of the Geological Survey, Scotland, for identifying the associated fossils. Further, my sincere thanks are due to the Keepers of the collections in the Sedgwick Museum, Cambridge, and in the Geological Department, British Museum (Natural History), for their kindness in permitting me to examine fossils of related species in their charge.

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Koninck, L. G. de, 1878. *Annales du Mus. Roy. d'Hist. Nat. de Belgique*, Tome II, Pt. 1, p. 115, pl. xxiv, ff. 2a, b.

McCoy, F., 1862. *Carboniferous Limestone Fossils of Ireland*, London, 20–22, pl. iv, f. 15.

Meek, F. B., and Worthen, A. H., 1870. *Proc. Acad. Nat. Sci. Philadelphia*, p. 49.

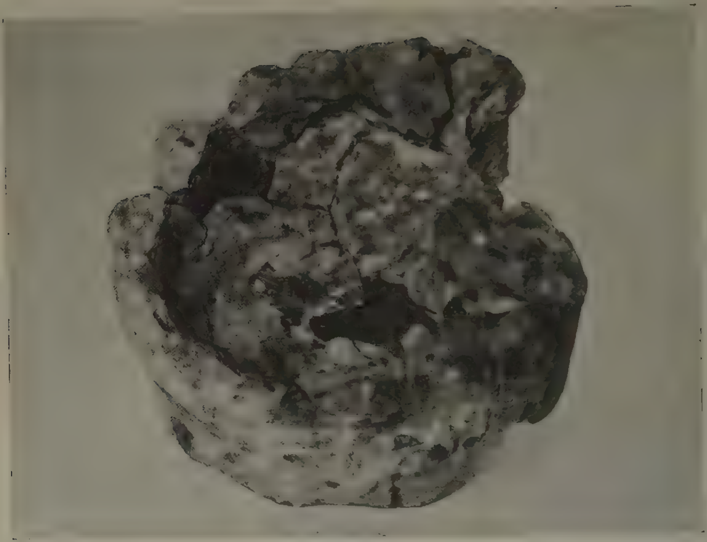

FIG. 1.

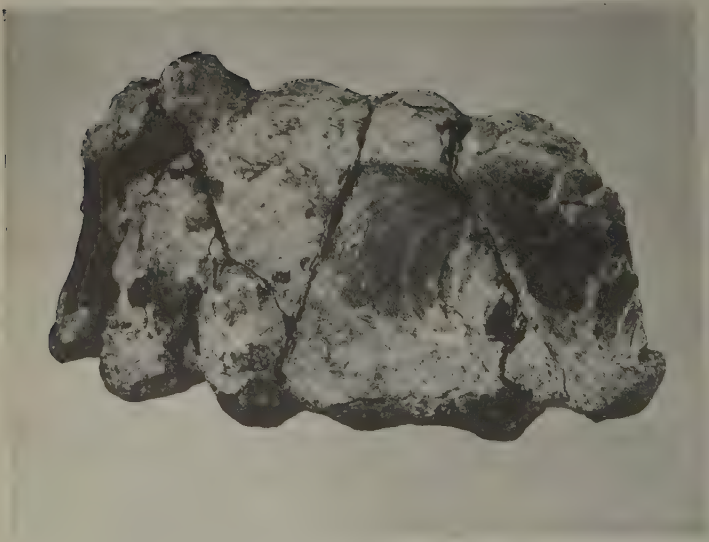

FIG. 2.

TEMNOCHEILUS VENTRO-CONCAVUS. sp. nov.

To face p. 459.

Miller, A. K., and Owen, J. B., 1934. *University of Iowa Studies*, xvi, no. 3, 221–5.
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EXPLANATION OF PLATE XVI.

Fig. 1.—Ventro-lateral view of *Temnocheilus ventro-concavus*, sp. nov. × $\frac{2}{5}$ approx.

Fig. 2.—Ventral view of adoral end of *Temnocheilus ventro-concavus*, sp. nov. × $\frac{1}{2}$. Replaced test on the right shows the extent of the hyponomic sinus.

On certain Anthracomyas from the Similis-Pulchra Zone of the Coal Measures.

By A. E. Trueman.

The genus *Anthracomya* was founded by Salter in 1861, and *Anthracomya adamsi* Salter which was then described on the basis of specimens from the Soap Vein of Penycae, South Wales, became the genotype. Wheelton Hind identified with this species a number of large shells from the Burnwood or Little Mine Ironstone of North Staffordshire (1895, p. 89, Pl. XII) but only occasional specimens from other coalfields and horizons have been referred to *A. adamsi*; Mr. J. H. Davies and the writer in 1927 (p. 233) recorded a somewhat similar form at a low horizon in the Pulchra Zone[1] of South Wales. They also pointed out that the North Staffordshire specimens exhibit a wider variation than those from the type locality, and that they are generally thicker and include variants of greater relative height (1927, fig. 6). Associated with these shells in Staffordshire were others which Hind identified with *A. dolabrata* (J. de C. Sow.) (1895, p. 94), a species which was founded on an imperfect specimen but which may be related to this group. Hind regarded these species as " very closely allied indeed ", and if his identifications are admitted there is no doubt as to this conclusion; in any event the specimens figured by him as *A. dolabrata* are probably variants of the group which includes the Staffordshire shells which he named *A. adamsi*.

The horizon at which these shells occur in North Staffordshire is a short distance above the Gin Mine Marine Band, above the middle of the Similis-Pulchra Zone (Davies and Trueman, 1927, p. 248).

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[1] It may be noted that this zone, as originally defined, has a lower limit quite different from the Pulchra Zone of Wright (1929, p. 52) and does not include his Pulchra sub-zone (1938B, p. 75.

Dr. E. Dix and the writer have pointed out that a comparable fauna, sometimes also containing forms designated *A. warei* Dix and Trueman, occurs above the marine bands at a corresponding horizon in Yorkshire and in South Wales (1931, p. 202), while Dr. W. B. Wright has recorded shells (which he has named *A. hindi* and which he regards as identical with those figured by Hind from the Burnwood Ironstone of Staffordshire) from above the Dukinfield Marine Band, at a similar horizon in Lancashire (1930, p. 41).

There is no doubt that these faunas show slight differences in different coalfields, but their utility in correlation has been evident; the writer has thought that any difficulties in their nomenclature would best be cleared up when more abundant and better preserved material was available from several areas. Recently, however, Dr. W. B. Wright (1938A, p. 15) has made further reference to *A. adamsi*, and in view of the confusion which may result from his comments on the species it appears desirable to clear away some misconceptions without further delay.

Wright's remarks may be quoted in full: "Now *Anthracomya adamsi* Salter (*non* Hind) has always been a most unsatisfactory species. Salter's figure is not remotely like the lectotype chosen by Trueman, and it is difficult to see that the latter differs in any appreciable degree from *A. modiolaris*. Any difference that exists is certainly within the limits of variation of *A. modiolaris*, and comparison suggests that, even if a distinction can ultimately be found, *A. adamsi* is certainly related to *A. modiolaris*, rather than to any form of *Anthracomya* characteristic of a higher horizon."

In the first place, it may be remarked with regard to this paragraph that since Dr. Wright nowhere in his paper refers to any publication by the writer, the reference to the choice of a "lectotype" of *A. adamsi* is somewhat vague. In a paper written jointly by Mr. J. H. Davies and the writer in 1927[1] reference was made to the types of *A. adamsi*, but neither in that paper nor anywhere else has a lectotype been chosen. Mr. Davies and the writer figured a specimen of *A. adamsi* which is certainly a topotype, which formed part of the Adams Collection from which Salter selected his example for illustration, and which appeared to those authors to be the specimen originally figured by Salter; they therefore suggested that it must be the holotype of the species. Even if it could be shown that this specimen is not the holotype, there is no doubt as to its locality and horizon being that of *A. adamsi*. If it does not differ "in any appreciable degree from *A. modiolaris*" it is most important for stratigraphical purposes that this should be made clear. The reasons for re-affirming the identity of this specimen with the example figured by Salter may first be discussed.

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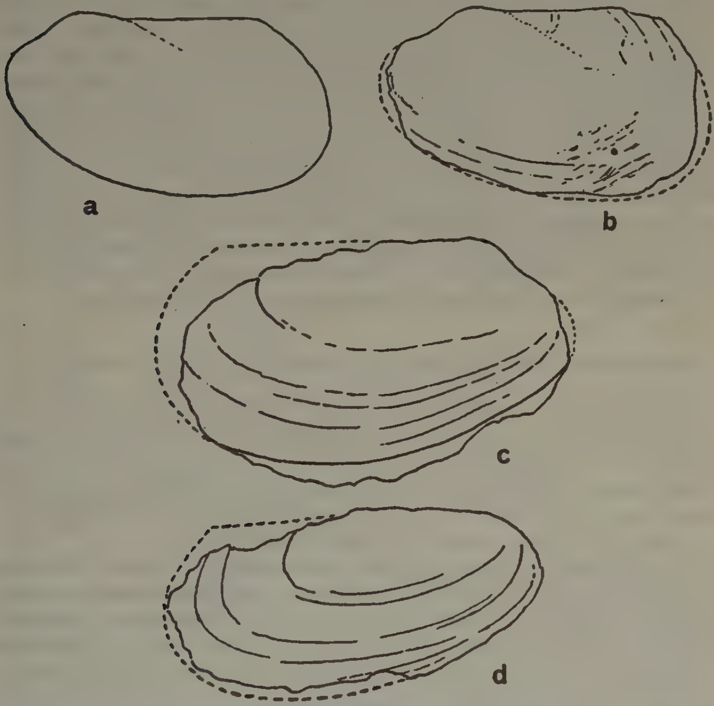
[1] Mr. Davies was also forgotten by Wright in his footnote on p. 11 of the same paper, where seven species credited to the writer were jointly named by Mr. Davies and himself.

THE HOLOTYPE OF *Anthracomya adamsi* SALTER

The specimen (National Museum of Wales, No. G683), regarded by Mr. J. H. Davies and the writer as the holotype of *A. adamsi* and illustrated in 1927, agrees very closely in side view with Salter's Pl. II, fig. 7*b*. It also agrees in dimensions; the specimen is somewhat incomplete, particularly at the posterior end, and the artist who drew Salter's figure has restored the missing parts (as he also appears to have done in the other shells on the same plate, all of which are represented as complete).



TEXT-FIG. 1.—*Anthracomya adamsi* Salter, from the Soap Vein of Penycae, South Wales (middle of Similis-Pulchra Zone). (*a*) Tracing of outline of Salters' original figure; (*b*) tracing from a photograph of the presumed holotype (Nat. Mus. Wales, G 683); (*c*, *d*) tracing of photographs of topotypes (Nat. Mus. Wales, G 685, G 684). All natural size.

In the accompanying Text-fig. 1*a*, *b*, is given a tracing of Salter's figure beside a tracing from a photograph of the presumed holotype: it will be noticed that in the drawing the anterior lower border is more curved than in the specimen. Otherwise the differences are no greater than are commonly found in illustrations made at that time; the artist has drawn the specimen with lighting from the top right-hand side, instead of the top left-hand side as is more usual, and the shading gives no indication of the contour of the anterior and lower part of the shell.

The identity of the specimen with that figured by Salter is most convincingly shown, however, by the wrinkling of the periostracum, which has a similar pattern and affects the same area in the specimen as in the drawing; in the complete drawing of the shell the wrinkles are inclined to the border at a higher angle than in the specimen, but the enlarged drawing of the wrinkles in Salter's Plate II, fig. 7*b*, shows them at a lower angle to the shell border, and this agrees exactly with that in the specimen. Not only is such correspondence in the markings absent in other topotypes in the Adams Collection, but the writer has not seen similar wrinkling in this position in any other specimen of *A. adamsi* or related species. Moreover, growth lines are present on the shell at the places where they are shown in the drawing. It appears to the writer to be beyond question that the specimen indicated is that from which Salter's drawing in Plate II fig. 7*b*, was made; as has already been suggested (Davies and Trueman, 1927, p. 233) the plan of the shell in Salter's figure (Plate II, fig. 7*a*) is inaccurate (unless it represents another specimen).

DISTINCTION OF *Anthracomya adamsi* FROM *A. modiolaris*.

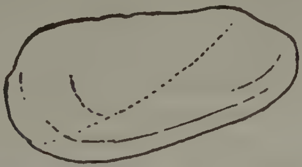
The specimen referred to above as *Anthracomya adamsi* is regarded by Dr. Wright as differing very little from *A. modiolaris*; "any difference that exists is certainly within the limits of variation of *A. modiolaris*." The distinction of these two species, however, is of great importance, for the former is characteristic of the Similis-Pulchra Zone, the latter of the Modiolaris Zone.

The distinction between the Anthracomyas typical of these horizons is readily made in the case of well preserved specimens and of the more characteristic species. The most important features include the shape of the shell outline (i.e. the side view of one valve) and the form of the lateral shell contour, especially with regard to ridge (or carina) and sulcus, if present.

The shape of shell outline is naturally of outstanding importance in the case of crushed shells, in which few other features may be available. Dr. Wright has drawn attention to the important fact that certain species characteristic of the Similis-Pulchra Zone have the maximum depth of the shell in a forward position as compared with many Anthracomyas of the Modiolaris Zone (1931, p. 145). It must be noticed, however, that numerous species in the higher zone have the position of the maximum depth as near the posterior end as is usual in the Modiolaris Zone. The position of maximum depth is thus very useful as regards certain species only, but it does not afford a basis for discriminating generally between the Anthracomyas of the two zones.

Some species of the Similis-Pulchra Zone (especially *A. adamsi* and *A. hindi* Wright) are also characterized by a greater proportional height than most species in the Modiolaris Zone, but there is considerable variation in this character. Thus *A. adamsi* is associated with shells in which the height is proportionally smaller than in the supposed holotype (see Text-fig. 1*d* and also Davies and Trueman, 1927, fig. 6, p. 232). On the other hand the lectotype of *A. modiolaris* is not nearly so high as the typical *A. adamsi*, although occasional variants of the *A. modiolaris* group are considerably higher.[1] So far as mere proportions are concerned, therefore, the variants of *A. modiolaris* tend slightly to overlap with those of the *A. adamsi* group: there may be other features in the shell outline which assist in their discrimination but they are not easy to define at this stage. There may in fact be a small number of crushed shells which cannot be finally classified (except by reference to the forms with which they are associated) but an assemblage of variants has never, in the writer's experience, presented any difficulty.

With "solid" shells, showing the lateral contour of the valves, the position is different. Fortunately both the lectotype of *A. modiolaris* and the specimen regarded as holotype of *A. adamsi* are solid and fairly complete The lectotype of *A. modiolaris* does not show the strong swollen carina, fronted by a wide sulcus, which characterizes such associated species as *A. curtata* (Brown), *A. robertsoni* (Brown) and *A. insignis* Davies and Trueman; its features are more subdued and thus appear at first sight to resemble those of *A. adamsi*. In neither of these species is there a recognizable sulcus, the anterior part of the shell being almost flat, while the carina or ridge is obscure. In *A. adamsi*, however, the "swelling" is wide and indefinite, and changes its slopes so gradually towards the front that it is difficult to fix its anterior border, only the upper posterior border being well marked (as in most solid Anthracomyas of the Similis-Pulchra Zone) whereas in the lectotype of *A. modiolaris* it appears to the writer that a faint angulation marks the front or crest of the narrower and more distinct swelling, as shown in Hind's figure (1895, Pl. XVI, 49). This distinction can be *felt* in the solid specimens but it is difficult to convey clearly in a description or in



TEXT-FIG. 2.—*Anthracomya modiolaris* (J. de C. Sow.), from Coalbrookdale. Tracing of Wheelton Hind's illustration of the specimen chosen as lectotype (Hind, 1895, xvi, 49).

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[1] Some of these more expanded shells resemble in outline *A. hindi* as closely as *A. adamsi* (see, for instance, Wright, 1938A, Text-fig. 5*a*).

any illustration. The crest of the swelling swings towards the posterior end of the shell, and is almost as prominent there as near the umbo.

It must be noticed, however, that it is only in less tumid members of these groups that these features are so subdued: in the thicker shells the same distinctions can be made but they are more pronounced, the sulcus in members of the *A. modiolaris* group tending to stretch backwards along the lower border much more than in the occasional members of the *A. adamsi* group in which a sulcus is developed. The slightly convex portion of the shell anterior to the sulcus is also larger and more distinct in members of the *A. modiolaris* group. While only a hint of these features can be "felt" in the lectotype of *A. modiolaris* they are sufficiently clear to distinguish that specimen from *A. adamsi*.

THE HORIZON OF *Anthracomya adamsi*.

The evidence concerning the horizon of *A. adamsi* is quite opposed to Wright's view that "*A. adamsi* is certainly related to *A. modiolaris* rather than to any form of *Anthracomya* characteristic of a higher horizon." It must in fact be emphasized that *A. adamsi* itself is a form of *Anthracomya* characteristic of the higher horizon in question.

The zonal position of the horizon of the type specimens, the Soap Vein of Penycae, was only approximately known in 1927 (Davies and Trueman, p. 244) when it was believed to be near the base of the Pulchra Zone, and possibly near the horizon of the Soap Vein of the west of the South Wales Coalfield; Wheelton Hind had previously been misled in a similar manner (Hind, 1895, p. 157). It has been clear for some time, however, that the Soap Vein of Penycae lies at a much higher horizon, nearer the middle of the Similis-Pulchra Zone. Dr. T. Robertson, in the revision of the Abergavenny and Merthyr Tydfil areas, showed that the Penycae Soap Vein is near the horizon of and almost certainly equivalent to the Gorllwyn seam or Blackband Ironstone, which lies just above the Cefn Coed Marine Band (Robertson, 1927, p. 95; 1933, pp. 147, 156). *A. adamsi* and allied forms have also been recorded from this horizon in several other parts of South Wales (W. D. Ware, 1930, p. 467; E. Dix, and A. E. Trueman, 1931, p. 182; W. H. Evans and B. Simpson, 1933, pp. 460–61).

Since the Cefn Coed Marine Band is regarded as the equivalent of the Mansfield Marine Band (and thus of the Dukinfield Marine Bed of Lancashire) the horizon of the holotype most probably lies within the group of strata which Wright has called the Hindi Subzone.[1] The occurrence of Anthracomyas of the *A. adamsi* group, sometimes accompanied by other species such as *A. warei* Dix and Trueman, has been regarded as characteristic of this horizon in several coalfields (Dix and Trueman, 1931, pp. 201–2; Trueman, 1933, pp. 78, 80).

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[1] The writer does not consider it desirable to use the term "Hindi Subzone" in the sense in which it is employed by Wright: he suggests that "band" would be a more suitable term. The subzonal terms which that author has introduced correspond to some extent with the general sequences which have been made out in South Wales, Yorkshire, and other coalfields, but the changes which he has recently made in the subzonal boundaries as well as other considerations indicate the need for caution in using these terms.

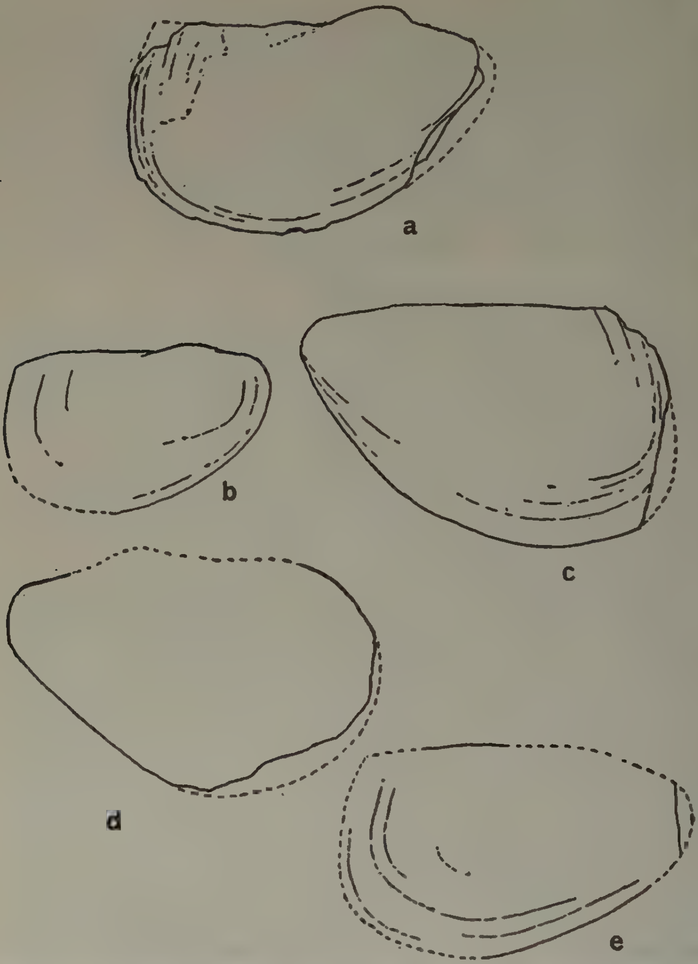
Forms resembling *A. adamsi* have also been noted at a lower horizon in South Wales (Davies and Trueman, 1927, p. 233; Ware, 1930, p. 473). The first named authors suggested that the shell differs in some respects from the holotype of the species and that it may be a variant of another group of Anthracomyas (*A. rubida*) which occurs at this lower level in the Similis-Pulchra Zone; possibly the species (and others related to it) originated at this or a lower horizon but it does not appear to have been recorded in the intervening strata.

THE VARIANTS OF *Anthracomya adamsi* AND SOME ASSOCIATED SPECIES.

The shells from the Soap Vein of Penycae in the Adams Collection in the National Museum of Wales include several forms which may be extreme variants of the *A. adamsi* stock or may represent different species. Most of them are not so high as the presumed holotype of *A. adamsi* but some have a more distinctly rounded lower border with the maximum depth further forward. One form shows a shallow sulcus: in this the anterior border of the carina is therefore more distinct. It differs also from the holotype in its more triangular shape, the anterior end being somewhat pointed and the lower border almost straight for some distance (Text-fig. 1*c*).

Some solid shells of this group were collected by Messrs. W. H. Evans and B. Simpson from what is believed to be an identical horizon, the Golden Seam in the Nantyffyllon area of South Wales (1933, pp. 460–1): these shells include a variety of large forms, some of which are almost identical with variants from the Soap Vein horizon of Penycae. One specimen (Swansea University Coll. L 2638) shows a weak sulcus, but most of the large examples are without a sulcus. They vary in the form of the posterior end, one (Swansea University Coll. L. 2643) being truncated, the angle β little more than 100 degrees. One specimen is very near *A. warei* Dix and Trueman as already noted by Messrs. Evans and Simpson: this is a more tumid shell and has the maximum depth in a markedly forward position. Smaller specimens from the same locality (Swansea University Coll. L 2639, 2641) are less oblique in form, but have a distinct inferior-posterior angulation: it is doubtful if they are closely related to the *A. adamsi* fauna.

At several localities in South Wales and elsewhere *A. warei* Dix and Trueman has been found at this horizon: it does not appear always to accompany *A. adamsi*, and it may therefore be a distinct species and not merely a variant of that group. It is a much thicker form than *A. adamsi*, with the lower border more evenly curved and with the maximum depth in a more forward position: the topotypes collected by Mr. W. D. Ware at Cefn Coed show much variation in these features (Dix and Trueman, 1931, fig. 1, p. 183 and Pl. XVII, figs. 12–15) but most of the examples are smaller than the usual specimens of *A. adamsi*.



Text-fig. 3.—*Anthracomya hindi* Wright, from above the Worsley Four Foot Mine, Nob End Brickworks, S.E. of Bolton, Lancs. (*a*) holotype (Geol. Survey Coll., 49129); (*b*, *c*, *d*, *e*) paratypes (Geol. Survey Coll., Nos. Hs 2239, Hs 2291, Hs. 2298, Hs 2207). Outlines traced from photographs: all approximately natural size.

The forms associated with *A. adamsi*, whether they are regarded as variants or distinct species, thus show marked differences in the several areas in South Wales where these faunas are known.

Anthracomya hindi AND ITS VARIANTS (TEXT-FIG. 3).

Anthracomya hindi was founded by Wright (1930, p. 44) to include *A. adamsi* Hind, which differs in some respects from the supposed holotype of *A. adamsi* Salter (Davies and Trueman, 1927, p. 233). Wright drew particular attention to the curvature of the ventral margin in *A. hindi* and to the forward position of the maximum depth, which he regarded as distinguishing it from the Anthracomyas of the Modiolaris Zone (1930, p. 45): only occasionally is there any danger of confusion between these forms, however (see footnote, p. 463). Dr. Wright did not suggest how *A. hindi* can be separated from *A. adamsi*, the species to which Hind referred his specimens, and which, as shown above, is now known to occur at an identical or very near horizon.

In relative height, the holotype of *A. hindi* differs little from *A. adamsi*; the holotype of the latter (Text-fig. 1*b*) has its maximum depth in a more posterior position and has a somewhat less curved anterior lower border. It is also a thinner shell, with the umbones less prominent and less raised above the hinge line; the thickest part of the shell is also nearer the hinge line than in the holotype of *A. hindi*. The shells are similar, however, in many respects. Apart from the difference in lower border they are similar in shape, while both lack any distinct carina.

When the variants of *A. hindi* are considered, however, these differences appear to be of less importance. There are two sets of variants available for study, Dr. Wright's topotypes and the specimens from the Burnwood Ironstone of Staffordshire figured by Hind (and named by him *A. adamsi*) which are now in the British Museum (Natural History). Dr. Wright's paratypes and topotypes from Lancashire are in most cases poorly preserved but they show considerable variation in the form of the anterior lower border, which in some cases is much straighter than in the holotype (e.g. Hs. 2298, shown in Text-fig. 3*d*). Hind's figures (1895, Plates XII and XIII) of the Staffordshire specimens show a still wider range of variation. The form of the lower border and position of the maximum depth vary greatly (compare Hind, Plate XII, fig. 5, with figs. 6 and 9), while there is also great difference in the relative thickness; the specimen shown in Plate XII, fig. 7, is thinner than the others, and resembles the holotype of *A. adamsi* in that character and in the less conspicuous umbones.

Dr. Wright moreover drew attention to the fact that some of the smaller specimens of *A. hindi* are shallower and "come nearer to possessing a postero-ventral angulation, and have the maximum depth a little further back" (1930, p. 45); in these features they tend to resemble the holotype of *A. adamsi*. Some of the specimens referred to *A. dolabrata* (J. de C. Sow.) by Hind (1895, Plate XIII, figs. 5–9 and 11) show a still closer approach to *A. adamsi* in these characters, although generally differing in thickness: the writer believes them to be variants at that horizon of the forms figured by Hind as *A. adamsi*.[1]

To sum up the position, it appears that the group of *A. hindi* as represented by Hind's specimens from Staffordshire shows a range of variation which overlaps with *A. adamsi s. str.* As the range of variation at different localities does not appear to be identical, it is probably useful to retain these separate specific names, but there can be no doubt as to the close affinity of *A. adamsi* and *A. hindi*. Moreover *A. warei* has apparently not been seen in Lancashire or in Staffordshire, but although it is smaller and thicker than *A. hindi*, it resembles that species in certain features of shell outline and is probably closely allied.

SUMMARY.

(1) Reasons are given for believing that the holotype of *Anthracomya adamsi* Salter (the genotype of *Anthracomya*) has been correctly identified.

(2) It is shown that the horizon of this presumed holotype is near the middle of the Similis-Pulchra Zone, and is near if not identical with the horizon of *A. hindi* Wright.

(3) *Anthracomya adamsi* at that horizon has no close connection with *A. modiolaris* (from which it may, however, have been derived at a lower horizon). The distinction of these two forms is discussed, and it is suggested that among well preserved specimens only very occasional variants cause any difficulty in identification. The shells referred to *A. adamsi. s. lat.* by Weir and Leitch from the base of the Similis-Pulchra Zone (1936) are not considered in this paper.

(4) The relations of *A. adamsi*, *A. hindi* and *A. warei* are briefly discussed: in view of the limited distribution of the various species it is thought best for the present to retain the three specific names.

In conclusion the writer wishes to express his indebtedness to Mr. C. P. Chatwin and Dr. W. B. Wright of the Geological Survey, to Dr. W. D. Lang and Mr. K. P. Oakley of the British Museum (Natural History), to Dr. F. J. North of the National Museum of Wales, and to Professor T. N. George and Mr. B. Simpson of University College, Swansea, for opportunities to examine specimens in their charge. He is also grateful to his colleagues Dr. John Weir and Mr. D. Leitch for helpful discussion and useful suggestions.

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DIX, E. and TRUEMAN, A. E. 1931. "Some Non-Marine Lamellibranchs from the Upper Part of the Coal Measures. *Ibid.*, lxxxvii, p. 180.

[1] It is quite possible that these shells are correctly referred to *A. dolabrata* (J. de C. Sow.), which may be a more tumid shell similar in shape to *A. adamsi s. str.* The holotype is incomplete and is difficult to interpret; its horizon appears to be below that of the holotype of *A. adamsi*.

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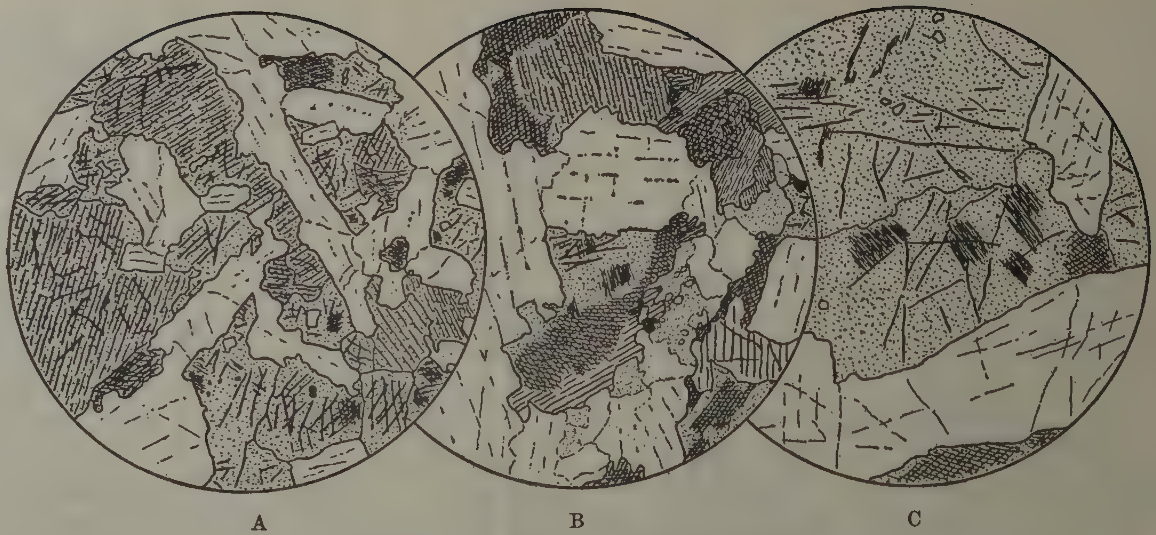
Contributions to the Petrology of Barnavave, Carlingford, I.F.S. 3: On some Hybrids from the E. and S.E. Slopes of Barnavave Mountain.

By S. R. Nockolds.

Introduction.

The rocks about to be described are found in various parts of the eastern and south-eastern portions of the eucrite mass which forms the bulk of Barnavave Mountain. They are best displayed, however, between the 700 and 800 foot contours in the area just north of the large N.W. fault which crosses the region.[1] The main characters of the normal eucrite are already well known from Sollas's now classical researches on the western side of the mountain.[2] The normal eucrite of the eastern part of Barnavave is very similar to that occurring in the west. It is composed essentially of a diallagic pyroxene and a basic plagioclase, with or without a small but variable quantity of rhombic pyroxene (Text-fig. 1a). The *plagioclase* varies from $Ab_{19}An_{81}$ to $Ab_{30}An_{70}$, but the bulk centres round the more acid of these extremes. When subjected to metamorphism by the later acid intrusions, it shows very fine

[1] See Sketch-map, Geol. Mag., LXXII, 1935, 290.
[2] W. J. Sollas, *Trans. Roy. Irish Acad.*, xxx, 1894, 477.



Text-fig. 1.—*Eucrite, east side of Barnavave.*

A. Eucrite with sub-ophitic texture. Ord. light × 10.

B. Eucrite slightly hybridized by quartzo-felspathic material. Quartz (clear) and potash felspar (stippled) may be seen on the right of the figure. Some hornblende is developing at the expense of the pyroxene in their neighbourhood. Ord. light × 10.

C. Coarse pegmatitic variety of the eucrite. Ord. light × 10.

"clouding" and may appear black in hand specimen. The *diallagic pyroxene* is almost colourless in thin section but has a pale brown colour in thicker pieces. It has $\alpha = 1{\cdot}680 \pm {\cdot}003$, $\gamma = 1{\cdot}703 \pm {\cdot}003$, $\gamma \wedge c = 41°$, $(+)\ 2V = 63° \pm 4°$, dispersion moderate $\rho > v$. A chemical analysis will be found on p. 477. In places it has a well defined schiller structure. The *rhombic pyroxene* (enstatite), when present, is colourless and non-pleochroic in thin section and also shows schiller structure. The *accessory constituents* include some titaniferous magnetite or ilmenite (normally enclosed in pyroxene). Apatite appears to be negligible in quantity. The texture of the rock is typically gabbroidal, sometimes with a tendency to assume a more doleritic habit. Rarely, it assumes a pegmatitic character (Text-fig. 1c). The felspar is hypidiomorphic and the pyroxene is either in interstitial plates or builds hypidiomorphic crystals. Small irregular grains of pyroxene are enclosed in felspar and the latter may also be enclosed as small crystals in the former. When enstatite is present in any amount there are interesting intergrowths between it and the monoclinic pyroxene, but these have already received attention elsewhere.[1] The average grain size of the monoclinic pyroxene is 1·7 × 1·1 mm., although it naturally reaches a much higher figure in the pegmatitic varieties. Throughout much of its outcrop the eucrite has been altered and impregnated by later quartzo-felspathic material (Text-fig. 1B). Analyses of two specimens are given below :—

	I	II	A	B
SiO_2 .	52·25	48·17	48·0	50·0
Al_2O_3 .	17·61	18·18	20·0	16·25
Fe_2O_3 .	4·04	2·63	9·0	11·0
FeO .	4·01	6·77		
MgO .	4·35	6·87	7·75	4·3
CaO .	13·05	14·03	12·0	10·5
Na_2O .	2·31	1·44	2·0	3·3
K_2O .	0·45	0·39	0·5	0·75
H_2O+ .	0·52	0·49		
H_2O- .	0·16	0·07		
TiO_2 .	0·58	0·49		
MnO .	0·06	0·07		
P_2O_5 .	0·10	Tr.		
	99·49	99·60		
Sp. Gr.	2·84	3·01		

Norms.

	I	II
qz. .	7·50	—
or. .	2·78	2·22
ab. .	19·39	12·05
an. .	36·42	41·98
di. .	21·88	22·23
hy. .	3·59	14·91
ol. .	—	0·93
il. .	1·22	0·91
mt. .	5·80	3·71
ap. .	0·34	—

I. Eucrite, S.E. side of Barnavave (slightly hybridized and impregnated with quartzo-felspathic material).

II. Eucrite, S.E. side of Barnavave (dark doleritic variety).

A and B are two averages taken from the variation diagram for the porphyritic central magma type of the British Tertiary province (see "Geology of Ardnamurchan, etc.," *Mem. Geol. Surv. Scot.*, 1930, 87).

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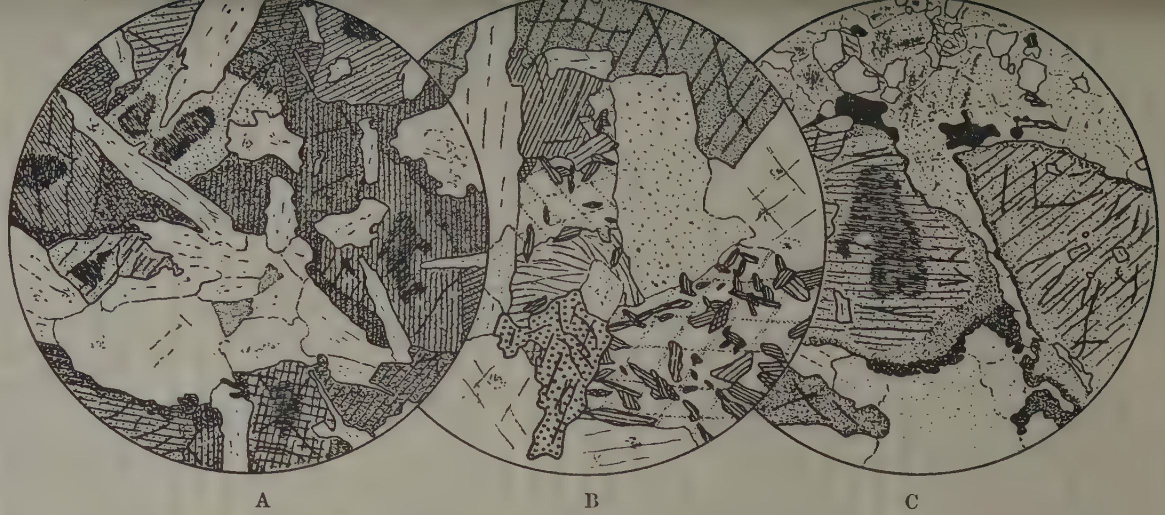
[1] W. J. Sollas, *loc. cit.*

THE HYBRIDS.

The hybrid rocks about to be described differ somewhat in appearance from the normal eucrite or its more usual impregnated varieties. They have a more definite black and white speckled appearance. Closer examination shows that they are traversed by minute veins of alkaline nature. These swell out in places to form small pools, and, in the immediate vicinity of these, the modified eucrite becomes coarser in grain and takes on an almost pegmatitic aspect. In their least altered form, the little veins are composed essentially of microperthite in small and larger grains together with a little calcite and prehnite. In specimens close to, or traversed by, these veins the pyroxene has taken on, for the most part, a noticeable though patchy colour (Text-fig. 2A). The major portion exhibits a brownish shade, but pale green areas are interwoven with this, and in some cases the green forms an outer margin to the brown variety. Normally, however, the green margin is absent and the crystals show continuous zoning, the brownish colour deepening from the centre to the margin. The schiller structure of the pyroxene is now confined to the almost colourless cores of the crystals. The highest extinction angle obtained here for this brownish pyroxene was $\gamma \wedge c = 55°$ with the pleochroic scheme $\alpha =$ dirty greenish brown, $\beta =$ yellowish brown, $\gamma =$ greenish, but the colours are variable to some extent. It has (+) $2V = 80° \pm 4°$, $\alpha = 1{\cdot}690 \pm {\cdot}003$, $\gamma = 1{\cdot}722 \pm {\cdot}003$. These values can only be regarded as approximations on account of the zoning and the difficulty of making certain that they were obtained on grains having the same colour intensity. In much of the pyroxene there are large numbers of long rod-like inclusions of iron ore, probably ilmenite. An analysis of the bulk chemical composition of the zoned pyroxene at this stage is given on p. 477. The green portions of the pyroxene often take on a spongy appearance towards their margins, due to the excretion of numerous small grains of sphene with subordinate magnetite. It is clear from a study of thin sections that the green pyroxene is being derived from the brownish variety and that the sphene granules represent a by-product thrown out during the reaction. A certain amount of green or blue-green hornblende with $\gamma \wedge c = 23°$ and $\alpha =$ light green, $\beta =$ brownish green, $\gamma =$ bluish green occurs at the margins of the pyroxene.

The plagioclase in these rocks is veined and zoned by a more acid variety and the felspar as a whole has become more acid, centring round $Ab_{45}An_{55}$, although some of the more basic plagioclase remains. In places it is much sericitized. Microperthite, introduced from the alkaline veins, may be present in quite large plates and some fair-sized but sporadic areas result. When hornblende, formed at the margins of pyroxene crystals, comes into contact with the microperthite it may take on a fibrous habit with narrow lamellae of



Text-fig. 2.—*Modified eucrite, east side of Barnavave.*

A. Modified eucrite showing colour zoning of the pyroxene and schiller structure confined to the cores of the crystals. A little interstitial microperthite is seen in the centre of the figure. Ord. light × 10.

B. Interstitial area, largely of introduced matter, in modified eucrite. The plagioclase and pyroxene of the eucrite are marginal in the figure. The centre is occupied by interstitial matter which includes microperthite (lightly stippled), ferriferous epidote (coarse stippling), a little prehnite (above the epidote), and calcite. The calcite encloses numerous little crystals of blue-green hornblende. Ord. light × 23.

C. Junction of modified eucrite with fine-grained granitic vein. The top portion of the figure shows the granitic vein, mostly composed of quartz and microperthite (light stippling). A narrow vein of microperthite is given off by the granite and may be seen traversing the modified eucrite in the lower part of the figure. At the bottom it widens out to form a small pool of microperthite in the modified eucrite. Note the marked colour zoning of the pyroxene against the microperthite. Ord. light × 23.

calcite lying between the fibres. In the larger areas of microperthite this mineral is accompanied by epidote, independent grains of blue-green hornblende and grains of colourless sphene. There are occasional patches of calcite filling up the interstices. These may be crowded with small idiomorphic crystals of the blue-green hornblende. In other instances the calcite is associated with prehnite and in yet others with epidote and a little albite (Text-fig. 2B). The epidote may be zoned with a deeply coloured outer rim, whilst the albite may hold minute, very long needle-like inclusions of a mineral which is taken to be apatite.

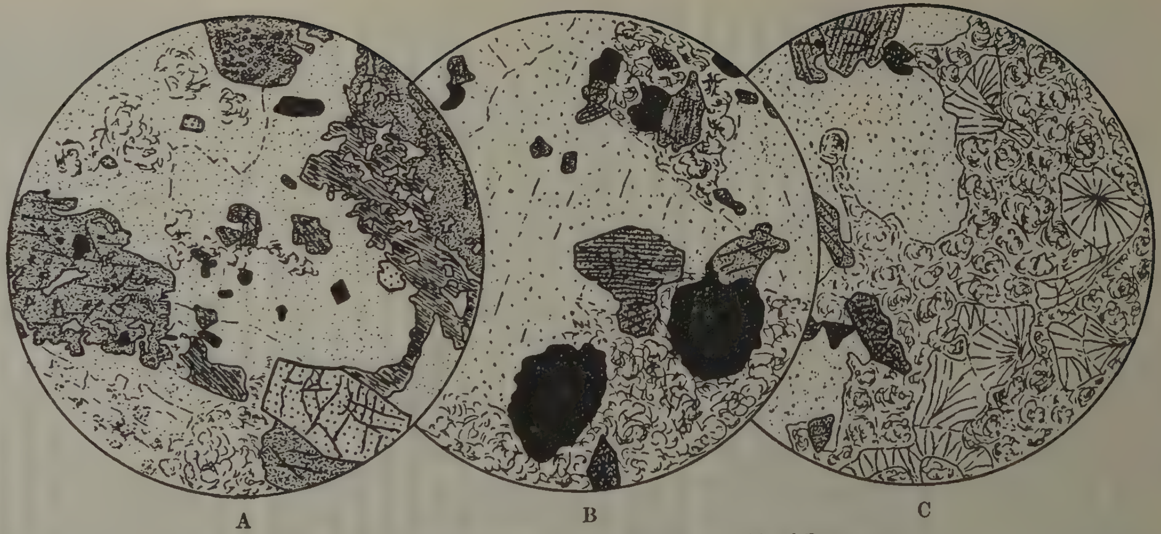
The most advanced stage of hybridization is found in the immediate vicinity of the alkaline pools already mentioned as being noticeable in the field. In the portions of the modified eucrite close to a pool the pyroxene shows marked zoning. The green pyroxene is better developed here and has often lost its spongy appearance, the sphene inclusions being either absent or else present as larger grains in the vicinity of the margin. The brownish pyroxene has much the same pleochroism as before, although its general colour is deeper. The green pyroxene has α = apple green, β = yellow, γ = yellow green, and the maximum extinction angle found was $\gamma \wedge c = 51°$. It has $\alpha = 1{\cdot}698 \pm {\cdot}003$, $\gamma = 1{\cdot}728 \pm {\cdot}003$, with (+) 2V somewhere about 80° but suitable sections for accurate determination were difficult to find. The pyroxene is replaced to a slight extent by very fibrous green or blue-green hornblende with which are associated minute granules of sphene and some secondary chlorite, together with a little magnetite and haematite. Other parts have little areas of the hornblende in definite crystals associated with epidote in crystals of comparable size, large grains of sphene, and a little microperthite. It is, however, the plagioclase which shows most change. It is intensely sericitized, so much so as to render determination difficult. It appears to have a composition lying between $Ab_{45}An_{55}$ and $Ab_{55}An_{45}$ but is also considerably zoned and acidified.

The pyroxene crystals are marginally intergrown with plagioclase and microperthite at the contact with an alkaline pool. The plagioclase is here more sericitized than ever and some of it is replaced by turbid prehnite. Some new plagioclase ($Ab_{82}An_{18}$) is formed in addition and contains an abundance of dusty inclusions. This new plagioclase seems to be arising, in part, from sericitized material representing the older plagioclase. Undoubtedly the most striking feature here is the large increase in grain size which affects both the pyroxene and the plagioclase, but which is specially noticeable in the former. The crystals of pyroxene may be as much as 12 × 6 mm. in size. This large increase only takes place in the immediate vicinity of the pools and is probably due to the recrystallization of the minerals in what was, essentially, a fluid medium.

THE ALKALINE POOLS.

There is a gradual transition from this bordering zone into the alkaline pool, the larger pyroxenes and reconstituted plagioclase becoming less abundant as alkaline material becomes more prominent. Where the large pyroxene crystals project into the pool they become strikingly idiomorphic. In the pools themselves (Text-fig. 3) microperthite occurs in large shapeless plates enclosing plagioclase and small idiomorphic crystals of green pyroxene, similar in pleochroism and extinction angle to that in the hybridized eucrite. The microperthite has a turbid appearance, is sometimes full of minute apatite needles, and may also contain needles of blue-green hornblende. The plagioclase ($Ab_{88}An_{12}$) is also turbid, may also contain needles of apatite, and is present in crystals of varying size. Idiomorphic, colourless or pale brown sphene and magnetite, together with a highly pleochroic epidote, are noticeable accessories, and apatite is also sporadically present in very long slender crystals or as fat stumpy prisms. Both the sphene and the apatite may be observed in hand-specimen, the former sometimes in quite large masses of a honey-yellow colour. In addition to these constituents there is a clear, colourless prehnite in little flakes, often with a semi-spherulitic fibrous arrangement, filling up the interstices between the other constituents. This interstitial prehnite may hold little highly coloured epidote needles and equally small prisms of blue-green hornblende. There is another type of prehnite present in the pools, and one which is considerably more abundant. This occurs as very turbid aggregates which are definitely replacements, both of plagioclase and microperthite. The turbidity of this secondary prehnite is caused by the minute dusty inclusions which were present in the felspars it has replaced. The two types differ slightly in refractive index, the turbid variety having $\alpha = 1{\cdot}615 \pm {\cdot}003$ whilst the clear variety has α just above 1·622. The first may make up as much as 37 per cent (by volume) of the pools, whilst the clear prehnite forms some 5 per cent (by volume) of the rock.

Ignoring the secondary prehnitization, the rock forming the alkaline pools might thus be described (were it a normal product) as an augite-syenite, rather rich in sphene and apatite in places. The presence of iron-rich epidote and interstitial prehnite indicates that the original magma was rich in volatiles and the rock has suffered from the effects of these. It is probable, in fact, that the prehnitization of the felspar took place at a period when the rock was almost entirely solid and when the clear prehnite was being deposited in the interstices. The narrow veins which feed the pools are also prehnitized to a considerable extent in a similar manner. A chemical analysis of one of these alkaline pools has been made and the result is given below :—



TEXT-FIG. 3. *Alkaline pool in modified eucrite, east side of Barnavave.*

A. Junction of pool with modified eucrite. The portions of large pyroxene crystals which are visible belong to the eucrite. One shows marginal alteration to hornblende. Note how they form a kind of intergrowth with the surrounding microperthite which occurs in the alkaline pool. The smaller pyroxene crystals have crystallized in the pool and the other constituents shown are iron-ore, a little sphene and apatite including one large crystal. Ord. light × 10.

B. Alkaline pool showing iron-ore, sphene, pyroxene, microperthite, and plagioclase which is replaced by aggregates of turbid prehnite. Ord. light × 23.

C. Alkaline pool with clear interstitial prehnite and turbid prehnite which has replaced plagioclase and microperthite. The remaining constituents shown are microperthite, pyroxene, sphene, and a little iron-ore. Ord. light × 23.

	III		*Norm.*
SiO_2	55·71	qz.	14·76
Al_2O_3	15·82	or.	20·02
Fe_2O_3	5·16	ab.	10·48
FeO	2·37	an.	27·52
MgO	1·01	di.	5·40
CaO	12·63	wo.	11·37
Na_2O	1·24	il.	1·82
K_2O	3·37	mt.	4·87
$H_2O +$	1·25	hae.	1·76
$H_2O -$	0·09	ap.	0·34
TiO_2	0·94		
MnO	0·02		
P_2O_5	0·09		
	99·70		

III. Alkaline pool in modified eucrite, E. side of Barnavave.

Discussion.

Owing to the rather variable composition of the rock, analyses of the modified eucrite are of little value for determining the changes which have taken place through the influence of the alkaline veins and pools. It was thought that the composition of the pyroxenes in these rocks might be more instructive and two chemical analyses of these are tabulated below :—

			No. of metal atoms on basis of 6 (*O, OH, F.*).						
	IV	V	IV				V		
SiO_2	50·63	46·88	Si	1·897	2·000		1·800	2·000	
Al_2O_3	3·28	4·69	Al	·103			·200		
Fe_2O_3	1·53	3·89	Al	·040	1·208	1·999	·012	1·123	2·025
FeO	8·92	10·67	Ti	·018			·060		
MgO	14·80	10·40	Fe^{111}	·040			·111		
CaO	19·34	19·78	Fe^{11}	·279			·341		
Na_2O	0·16*	0·79	Mg	·831			·599		
K_2O	—	0·58	Ca	·778	0·791		·814	0·902	
$H_2O \pm$	0·88	0·49	Na	·013			·060		
TiO_2	0·63	2·08	K	—			·028		
MnO	0·10	0·05							
	100·27	100·30							

* Total alkali as Na_2O.
IV Diallagic pyroxene from normal eucrite.
V Bulk composition of zoned augite from modified eucrite traversed by narrow alkaline veins.

It will be noticed immediately that the pyroxene from the normal eucrite bears a most striking resemblance to that found in the gabbro of Skye.[1] The replacement of Si^{++++} by Al^{+++} and the replacement of Ca^{++} by Na^{+} is balanced by a replacement of $(Mg, Fe)^{++}$ by Al^{+++}, Fe^{+++} and Ti^{++++}. If the pyroxene of the modified eucrite be compared with that of the normal eucrite it is apparent that there has been a relative decrease of SiO_2 and MgO with a corresponding increase of Al_2O_3, Fe_2O_3, FeO, TiO_2, and alkalies together with a very slight increase of CaO. From the point of view of the structural formulae these changes result in an increased replacement of Si by Al, a nearer approach of the Y group to the theoretical pure diopside value of 1, and a corresponding approach of the X group to this same value. The increased replacement of Si^{++++} by Al^{+++} and of Ca^{++} by $(Na, K)^{+}$ is again balanced by further replacement of $(Mg, Fe)^{++}$ by Ti^{++++}, Fe^{+++} and a little Al^{+++}.

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[1] A. Harker, "Tertiary Igneous Rocks of Skye," *Mem. Geol. Surv. U.K.*, 1904, 108.

When we reflect that the pyroxene from the modified eucrite is zoned and frequently has almost colourless cores, it is evident that these changes must be still further emphasized in the outer zones of the crystals. There is thus evidence from the analyses of the pyroxenes that they have gained Al_2O_3, iron, alkalies, and TiO_2 during the hybridization process and have lost a certain amount of SiO_2 and MgO. The modified eucrites also contain iron-rich epidote and sphene, whilst the plagioclase has been rendered more albitic. Taking these facts as a whole we may justifiably reach the conclusion that the modified eucrites have gained a measure of iron, titanium, and alkalies from the alkaline veins. The Al_2O_3 may have been provided by that set free during the acidification of the plagioclase and the silica released by the pyroxene may have been utilized in this reaction. The narrow veinlets show little evidence of any reciprocal effect due to the influence of the eucrite, but in the alkaline pools the pyroxene and plagioclase have probably been formed, in part, with the aid of CaO and MgO released from the eucrite.

THE ORIGIN OF THE VEINS AND POOLS.

The general appearance of the alkaline veins and pools is so different from that of the normal quartzo-felspathic veins which frequently traverse the eucrite elsewhere, that they were at first regarded as probably representing a late alkaline differentiate from the magma which gave rise to the eucrite and of somewhat earlier date than the granitic veins. However, at the locality already mentioned, lying between the 700 and 800 ft. contours, a vein of fine-grained granite was found traversing the modified eucrite, and from this minute veinlets of alkaline nature were running out into the surrounding eucrite (Text-fig. 2c). The granite vein is rich in turbid microperthite with subordinate quartz (containing large fluid inclusions) and a small amount of plagioclase which is largely xenocrystal in nature. The dark minerals are represented by a little green pyroxene, not unlike that found in the alkaline pools, and a little xenocrystal augite. An interesting feature of the rock is the occurrence of an appreciable quantity of colourless fluorspar replacing the quartz. The little veinlets which are given off by this vein and traverse the surrounding eucrite are composed almost entirely of turbid microperthite with very minor amounts of calcite and prehnite. It is thus apparent that the alkaline veins are related to the granite. Some further confirmation of this is afforded by the occasional presence of prehnite associated with quartz and microperthite in some of the eucrite which has been more normally hybridized by the granitic magma.

COMPARISON WITH OTHER EXAMPLES.

It would not be proper to conclude without mentioning the close resemblance between these hybrids and the augite diorite found E.S.E. of Camphouse, Ardnamurchan.[1] In its coarse but variable texture, the occurrence of brownish and greenish zoned pyroxenes, interstitial plates of microperthite, and abundance of light brown sphene in masses easily visible in hand specimen, it is very similar to the more altered portions of the modified eucrite. The alkaline pools, with their abundance of prehnite, appear to be absent in the Ardnamurchan example. The rock is regarded as a hybrid and there are several other similar occurrences described[2] where a hybrid origin is obvious.

REVIEWS.

A DESCRIPTIVE PETROGRAPHY OF THE IGNEOUS ROCKS. Vol. IV, Part I: The Feldspathoid Rocks. Part II: The Peridotites and Perknites. By A. JOHANNSEN. pp. xvii + 523, with 180 illustrations. University of Chicago Press, 1938; (Great Britain and Ireland: Cambridge University Press). Price 21*s*. net.

PART I of the final volume of this series describes the feldspathoid-bearing rocks of Families 13 to 25 of the author's classification, ranging from rocks with unessential amounts of feldspathoids to the feldspathoid-rich rocks of Families 21 to 25. The descriptive matter follows the scheme of the earlier volumes, a tabulation of each Family being followed by descriptions of the rocks—definition and history, megascopic and microscopic characteristics and chemical compositions with (as far as possible) modes of analysed rocks. The interest always aroused by the alkaline rocks, so disproportionate in comparison with their importance in the field, is well brought out by the 395 pages of Part I of the present volume, only a few pages less than Vol. II on the quartz-bearing rocks and 40 pages more than are devoted to the "intermediate" rocks of Vol. III. Here, too, we get the same disproportion of varietal names, and the author himself ventures to add (albeit often somewhat diffidently—" if a name is desired, perhaps *columbretite* will serve ") twenty or more new names in the course of his descriptions. As explained in the Preface, rocks undoubtedly metamorphic have been omitted, and also those with a large percentage of calcite which " we may . . . dismiss . . . as non-igneous ".

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[1] "Geology of Ardnamurchan, etc.," *Mem. Geol. Surv. Scot.*, 1930, 153.
[2] *Op. cit.*, 228, 293, 311.

The 73 pages of Part II describe the peridotites and perknites, subdivided on the basis of the percentage of ores present and on the ratio of the olivine to the pyriboles. Included under Olivinites of Family 2 we find Eulysite, though with the comment that it may possibly be a metamorphosed rock. Throughout both parts of the present volume are continued the photomicrographs of type rock-sections and the portraits of well-known petrographers which were attractive features of the earlier volumes.

Thus we reach the end of a monumental contribution to petrographic literature. The collection of material for what was intended as both petrology and petrography began, the author tells us, nearly thirty years ago, but with growing bulk the petrological portions were laid aside—

> " And so I penned
> It down, until at last it came to be,
> For length and breadth, the bigness which you see."

What that bigness means to the present-day petrographer can perhaps best be appreciated by an examination of the combined Indexes to Vols. II, III, and IV, which conclude this volume. Seven pages of triple columns of an Index of Authors list over 800 names, and it is interesting to note how largely bulk the page references below the classic names—Rosenbusch and Zirkel, Brögger, Washington, and Lacroix. An Index of Localities cites about 2,500 occurrences with bold-face type to indicate a figured rock. Finally, 12 pages of double columns of an Index of Rock Names bring vividly before the petrographer the burden of nomenclature which he inherits, for there are included here over 500 distinct rock names (mainly derived from localities) which in themselves convey no descriptive information, apart from a host of hyphenated derivatives and the systematic names derived from the author's classification. Many of these names are, of course, recognized as redundant—" between some of the rocks with different names, there is about as much difference as between Tweedledee and Tweedledum "—but the author aims to include in a work put forth as a handbook rather than as a textbook every rock term whose position could be determined. This completeness is only one valuable feature of a great achievement, which stands as a monument to the width of the author's grasp of the literature and which must remain a standard work of reference for many years.

F. C. P.

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ORIGINAL ARTICLES.

The Evolution of the Criffell-Dalbeattie Quartz-diorite: A Study of Granitization.

By Malcolm MacGregor. University College, London.

I. Introduction.

THE transformation of sedimentary rocks to a rock of quartz-diorite aspect and mineralogy by a process of granitization, characterized by the introduction of an alkali-felspar magmatic fluid, has recently been described by the writer from the western end of the Criffell-Dalbeattie igneous complex (1937, pp. 471–7).[1] In the present paper the geochemistry of this process is considered in the light of supplementary analytical data.

The sense in which certain terms will be used is as follows :—

Granitization includes all processes whereby pre-existing rock is converted to quartz-dioritic product. It covers all the effects of interaction between insurgent (rising) " parent-magma " and country-rocks.

Parent-magma is regarded as an energized aqueo-silicic melt containing the constituents of alkali-felspars, but subject to modification in respect of both energy and composition during continuous reaction with its environment.

Emanation implies tenuous (vapour or gas) material which advances ahead of the parent-magma through the pore spaces of the country-rocks. Its composition and reactivity vary according to the nature of the country-rock and the distance from the magmatic source from which it emanates.

Mixed-magma is the resultant of the granitization process. It is a " mush " consisting of parent-magma together with solid material derived from the modified country-rocks.

Recent work has led to the conclusion that many granodiorites and quartz-diorites occurring in orogenic belts could not have crystallized from liquids of corresponding composition : both field evidence and laboratory investigation indicate that they originated by granitization of the country-rocks. The term " igneous " is inappropriate for these products of granitization, and an alternative term, " syntectic," has been proposed by Barth (1936, p. 836), who later adopts the term " migmatic " used by Wegmann (1936,

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[1] Numbers in parentheses refer to References at end of paper.

p. 307) to describe such rocks. The latter term has the advantag that it does not imply actual melting. However, “migmatite” was originally used by Sederholm (1907, p. 110) for a composit gneiss, and the term “mixed” is used in the present paper in plac of migmatic for rock which is the homogeneous product o granitization.

Under ideal conditions, the study of granitization would requir suites of serial rock specimens ranging from unaltered country rock to final “mixed” product. Further, ideal conditions woul presume essential uniformity (chemical, mineralogical, and textural of the country-rocks. Even under the best conditions, irregularitie in progressive reconstitution are often attributable to lack o original uniformity; evidence of transition from one term t another may be obscured or obliterated by rheomorphic movemen of the softened mass against the immobilized walls, or by deuteri changes (hydrothermal, pneumatolytic, etc.) during the wanin stages of igneous activity; and for physico-chemical reasons no yet clearly understood, granitization effects on country-rocks ar produced by certain magmas but not by others, and the intensit of granitization may vary at different contacts of the same magma.

Studies of granitization, in areas where the field evidence is a least free from ambiguity, have been made recently by severa workers. Backlund (1936), for example, has described the granitization of quartzites and limestones by emanations rich in potash soda, and alumina. The conversion of quartzite to syenite an appinite by “granitic” emanations, allied with “cafemic” emanations from ultra-basic magma, has been described by Miss Reynold (1936). Anderson (1937) has described the granitization of phyllites The literature contains abundant field, laboratory, and geochemica evidence bearing on the problem and on the evolution of hybrid in general, in particular the classical work of Lacroix and the Frenc school in the Pyrenees and of Sederholm in Finland, Eskola (1913) Fenner (1914), Read (1925, p. 21–51), Shand (1927, pp. 56–71) Grantham (1928), Brammall & Harwood (1932), Thomas & Smit (1932), Nockolds (1932), Daly (1933, pp. 293–301), and man others.

II. GRANITIZATION.

The quartz-diorite at the western end of the Criffell-Dalbeatt complex is emplaced in Silurian sediments which were steepl folded along N.E.–S.W. axes prior to the igneous activity. The strik of the rocks is preserved without deflection up to the contact the quartz-diorite. The unaltered sediments comprise (*a*) greywackes, usually a foot or two in thickness, and (*b*) shales, in 1 in. 2 in. bands alternately rich and poor in calcareous mineral matte Gradations occur between the various kinds of sediment, but thre main rock types serve for the present study: (1) greywack (2) poorly calcareous shale, and (3) richly calcareous shale.

The granitization of the sediments, considered broadly, takes place by two processes; (*a*) metasomatism, induced by permeating magmatic emanations, and (*b*) mechanical mixing of the metasomatized material with parent-magma, accompanied by chemical reaction with that magma. The first process involves a gradation from ordinary thermal metamorphism, with negligible gains or losses of substance, into metamorphism characterized by marked changes in both mineral and bulk composition. The second process leads to the formation of a mobile plastic mass—the "mixed-magma" of quartz-dioritic composition—consisting of fluid parent-magma and solid xenolithic material. The two processes have been recognized by Fenner (1914), Barth (1936), Kleeman (1937), and many other workers on granitization.

TABLE I.

Poorly Calcareous Shales.

	Analyses.			Constituents in grams per 100 c.c.			Losses and Gains in grams per 100 c.c.	
	Low Grade	Medium Grade.	High Grade.					
	A	B	C	A′	B′	C′	A′–B′	B′–C′
SiO_2 .	54·05	54·40	58·37	147·6	152·2	163·4	+ 4·6	+ 11·2
Al_2O_3	16·72	18·29	15·88	45·6	51·2	44·5	+ 5·6	− 6·7
Fe_2O_3.	1·04	0·79	1·21	2·8	2·2	3·4	− 0·6	+ 1·2
FeO .	5·90	6·81	5·33	16·1	19·1	14·9	+ 3·0	− 4·2
MgO .	5·84	5·76	5·01	15·9	16·1	14·0	+ 0·2	− 2·1
CaO .	3·72	4·55	4·60	10·1	12·7	12·9	+ 2·6	+ 0·2
Na_2O .	1·50	1·72	2·50	4·1	4·8	7·0	+ 0·7	+ 2·2
K_2O .	3·02	5·74	4·48	8·3	16·1	12·5	+ 7·8	− 3·6
H_2O +	4·92	1·24	1·50	13·4	3·5	4·2	− 9·9	+ 0·7
H_2O −	0·50	0·25	0·40	1·4	0·7	1·1	− 0·7	+ 0·4
CO_2 .	2·09	*nil*	*nil*	5·7	—	—	− 5·7	—
TiO_2 .	0·66	0·64	0·78	1·8	1·8	2·2	—	+ 0·4
MnO .	tr	tr	0·09	—	—	0·3	—	+ 0·3
P_2O_5 .	0·21	0·21	0·17	0·6	0·6	0·5	—	− 0·1
	100·17	100·40	100·32	273·4	281·0	280·9	+ 7·6	− 0·1
S.G. .	2·73	2·80	2·80					

A. Shale outside aureole (2161). Roadside quarry, ¾ mile N.E. Dundrennan. Very fine-grained rock in which sericite and biotite flakes can be distinguished microscopically. Small quartz grains in coarser layers and a little calcite.

B. Pelitic layer of banded shale hornfels (1864 B) 100 yards from contact, Mid Hill. Consists of biotite, quartz, andesine, and a little orthoclase and diopside (see MacGregor, 1937, p. 470 and fig 3, C).

C. Pelitic layer of banded shale hornfels (1865 B) at the contact, Mid Hill. Coarser than B, consisting of biotite, a little diopside partly converted to green amphibole, andesine, quartz, and poikilitic crystals of orthoclase (see MacGregor, 1937, pp. 471–2, and fig 3, A).

Analysts: alkalis by Geochemical Laboratories, the rest by W. H. Herdsman.

(a) *Metasomatism.*

Field observations and microscopic details relating to the metamorphism and granitization of the sedimentary rocks have been given elsewhere (MacGregor, 1937, pp. 468–476). Briefly the unaltered greywackes consist of clastic grains of quartz and scanty plagioclase set in plates of calcite and chloritic matter. The unaltered shales are fine-grained and differ from the greywackes essentially in the absence of clastic grains. The progressive metamorphism of these rocks follows the normal course. Crystalloblastic growth gradually increases the grain size. In the less calcareous types biotite arises and in the more calcareous types amphibole evolves at medium grade; diopside at higher grade of metamorphism. From the mineral assemblage alone, however, little can be inferred concerning change in bulk composition. The analytical data, given in Tables I, II and III, provide this information.

TABLE II.

GREYWACKES.

	Analyses.			Constituents in grams per 100 c.c.			Losses and Gains in grams per 100 c.c.	
	Low Grade.	Medium Grade.	High Grade.					
	D	E	F	D′	E′	F′	D′–E′	E′–F′
SiO_2 .	53·91	63·42	66·95	147·2	180·1	190·1	+ 32·9	+ 10·0
Al_2O_3	7·55	13·34	11·31	20·6	37·9	32·1	+ 17·3	− 5·8
Fe_2O_3.	0·34	0·04	1·24	0·9	0·1	3·5	− 0·8	+ 3·4
FeO .	3·43	4·50	4·02	9·4	12·8	11·4	+ 3·4	− 1·4
MgO .	2·37	3·21	3·44	6·5	9·1	9·7	+ 2·6	+ 0·6
CaO .	15·46	9·25	8·02	42·1	26·3	22·8	− 15·8	− 3·5
Na_2O .	1·94	2·08	1·92	5·3	5·9	5·5	+ 0·6	− 0·4
K_2O .	1·85	2·68	1·90	5·0	7·6	5·4	+ 2·6	− 2·2
$H_2O +$	1·35	0·47	0·40	3·7	1·3	1·2	− 2·4	− 0·1
$H_2O -$	0·07	0·20	0·25	0·2	0·6	0·7	+ 0·4	+ 0·1
CO_2 .	10·30	*nil*	*nil*	28·2	—	—	− 28·2	—
TiO_2 .	0·88	0·86	0·69	2·4	2·4	2·0	—	− 0·4
MnO .	0·24	0·12	0·08	0·7	0·3	0·2	− 0·4	− 0·1
P_2O_5 .	0·77	0·14	0·14	2·1	0·4	0·4	− 1·7	—
	100·46	100·31	100·36	274·3	284·8	285·0	+ 10·5	+ 0·2
S.G. .	2·73	2·84	2·84					

D. Greywacke (1730), half a mile S.W. of Blackbreast on edge of aureole. Consists of quartz grains and scanty oligoclase, with a little biotite, muscovite and orthoclase, and plates of calcite in a fine base of chloritic and sericitic material (see MacGregor, 1937, p. 469, and Anal. 9, Table III).

E. Greywacke hornfels (1863) 100 yards from contact, Mid Hill. Consists of quartz, diopside, plagioclase, orthoclase, and a little biotite and hornblende.

F. Greywacke hornfels (1866 A) at the contact, Mid Hill. Similar to E, but coarser grained.

Analysts of E and F: alkalis by Geochemical Laboratories, the rest by W. H Herdsman.

The specimens analysed were selected to represent (i) three stages or grades in the progressive reconstitution of the poorly calcareous shales and greywackes and (ii) two stages in the reconstitution of the calcareous shale type. For the purposes of comparison the analyses have been recalculated to grams per 100 c.c., and the losses and gains assessed on the same basis.

Some of the variation in each suite may certainly be attributed to original differences in composition. This is especially true in respect of FeO, MgO, and CaO; but initial variation does not obscure the general trends of progressive change, which can only be explained in terms of chemical alteration during metamorphism and reconstitution. Assuming that the variable content of FeO and MgO is an original feature, the most notable changes are tabulated in Table IV. If the variability of CaO is also taken as being original, and the analyses be compared on the basis of equal CaO content, the losses and gains still have the same significance.

TABLE III.

CALCAREOUS SHALES.

	Analyses.		Constituents in grams per 100 c.c.		Losses and Gains in grams per 100 c.c.
	Medium Grade.	High Grade.			
	G	H	G′	H′	G′–H′
SiO_2	57·79	59·73	173·4	176·8	+ 3·4
Al_2O_3	12·24	12·22	36·8	36·2	− 0·6
Fe_2O_3	0·98	1·86	2·9	5·5	+ 2·6
FeO	4·89	5·59	14·7	16·5	+ 1·8
MgO	4·23	3·73	12·7	11·1	− 1·6
CaO	17·42	10·92	52·3	32·3	− 20·0
Na_2O	0·66	1·64	2·0	4·9	+ 2·9
K_2O	0·36	1·64	1·1	4·9	+ 3·8
H_2O +	0·34	1·13	1·0	3·3	+ 2·3
H_2O −	0·20	0·07	0·6	0·2	− 0·4
CO_2	0·59	*nil*	1·8	—	− 1·8
TiO_2	0·76	0·87	2·3	2·6	+ 0·3
MnO	0·18	0·15	0·5	0·4	− 0·1
P_2O_5	0·16	0·18	0·5	0·5	—
	100·80	99·73	302·6	295·2	− 7·4
S.G.	3·00	2·96			

G. Calc-shale hornfels (1864 A) 100 yards from contact, Mid Hill. Consists of diopside, quartz, oligoclase-andesine, and a little biotite and potash felspar (see MacGregor, 1937, p. 470 and fig. 3, C).

H. Calc-shale hornfels (1865 A) at the contact, Mid Hill. Similar to G but coarser grained and with the addition of some green hornblende and epidote (see MacGregor, 1937, p. 471 and fig. 3, A).

Analysts: alkalis by Geochemical Laboratories, the rest by W. H. Herdsman.

The following deductions are made from a study of the serial analyses combined with the knowledge of the rocks in the field and in the laboratory :—

(1) Reconstitution of the aureole sedimentary rocks is accompanied by change in bulk composition. In both the greywackes and the poorly calcareous shales potash and alumina increase at medium grade and decrease again at high grade : A zone of potash and alumina enrichment is thus distinguishable. This may indicate greater diffusibility of these constituents compared with others. Differential diffusibility of materials has been postulated by most workers dealing with granitization. For example, Brammall & Harwood (1932, pp. 195–6), Miss Reynolds (1936, pp. 397), Wilson (1938, pp. 211–2), and Backlund (1936, p. 343).

(2) Carbon dioxide is eliminated at an early stage as would be expected in normal thermal metamorphism, but water content after decreasing in medium grade tends to increase again in high grade. The introduced material was therefore probably hydrous.

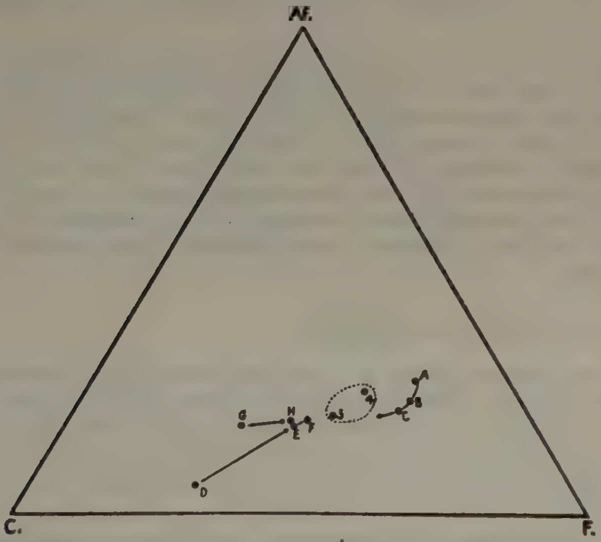
TABLE IV.

	Low to Medium Grade.		Medium to High Grade.	
	Increase.	Decrease.	Increase.	Decrease.
Poorly Calcareous Shale Type	Al_2O_3 K_2O CaO	H_2O CO_2 —	SiO_2 Na_2O Fe_2O_3	K_2O Al_2O_3 —
Greywacke Type	SiO_2 Al_2O_3 K_2O	CO_2 H_2O CaO	SiO_2 Fe_2O_3 —	K_2O Al_2O_3 CaO
Calcareous Shale Type	— — —	— — —	K_2O Na_2O Fe_2O_3	CaO — —

(3) The progressive changes in composition as traced across the aureole towards the quartz-diorite are not simply the additive effects of permeation by the parent-magma as a whole, but represent the effects of metasomatic exchanges between the mineral constituents of the country-rocks and their pore liquids augmented by an advance fraction of the parent magma—emanations—such as have been described by Lacroix (1898 and 1900), Fenner (1914), Barth (1936, p. 833), and others. The emanations consist essentially of Al_2O_3, SiO_2, K_2O, Na_2O, Fe_2O_3, with H_2O.

With progress towards the contact the amount and energy of the pore-contained liquid increases and its composition changes, due both to increased solution and to the addition of material from the advancing magma front. At any particular energy level such material as tends towards the attainment of equilibrium between the mineral phases of the country rock and the contained pore liquid is " fixed ". The metasomatism is thus selective and is not directly dependent on either the composition of the emanations or the mineral composition of the country-rock, taken separately, but on both these factors in relation to each other, as well as on the particular energy level concerned.

(4) Looked at from a broad point of view, the material fixed was of such a character as to convert the initial rock progressively towards a mineral assemblage and a bulk composition convergent towards that of the final product, i.e. the quartz-diorite. The serial analyses show this metasomatic convergence of originally differing rock types towards the composition of the quartz-diorite. It is well exhibited in the plotting of the analyses on an Af.C.F. basis (Text-fig. 1).



Text-fig. 1.—Af/C/F plotting of the analyses to show metasomatic convergence; A, B, and C, poorly calcareous shale hornfelses (Table I). D, E, and F, greywacke hornfelses (Table II). G and H, calcareous shale hornfelses (Table III). 3 and 4, normal quartz-diorites (MacGregor, 1937, p. 459, Anals. 4 and 5).

The mechanism of metasomatism is difficult to explain in the present state of knowledge concerning the behaviour of materials at high temperatures and pressures. Van Hise (1904, pp. 63–5) points out that chemical reaction in rocks must take place through the agency of the pore-contained liquid. Harker (1932, p. 14) also stresses the importance of pore-liquid during metamorphism.

Barth (1936, pp. 831–2 and 840–2) discusses metasomatism in connection with the formation of "mixed" or syntectic rocks, and the present study leads the author to agree with his conclusions as to the mechanism of the process. He says (1936, p. 842, footnote) that "the mechanism of the recrystallization processes in a metamorphic rock is the same as the metasomatic replacement process in a syntectic rock; but in the metamorphic rock the liquid acted only as a catalyst, promoting processes without changing the chemical composition of the rock. In the syntectic rock, however, the liquid acted metasomatically, thereby changing the initial composition of the rock. To bring out this difference, metamorphism may be considered as a metabolism of the rock, syntexis as a metasomatism of rock".

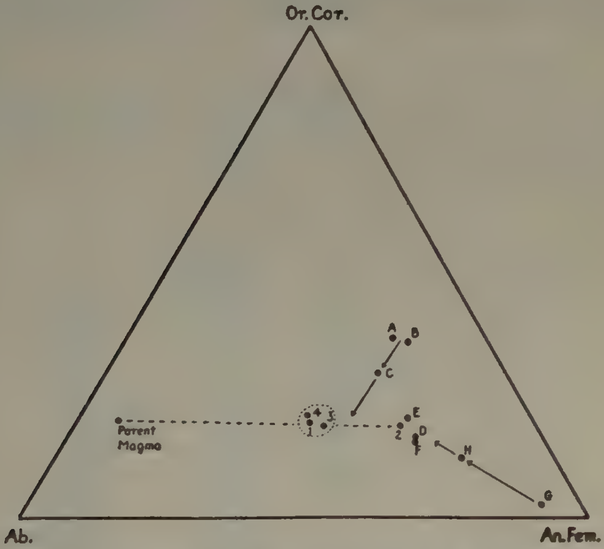
The pore liquid must be hydrous and possibly the materials of the emanations are carried in it as solutions of the oxides, though as yet there is no experimental basis for deciding in what form they may exist. The role of water either as liquid or gas is certainly of great importance in enabling chemical reactions to take place both during thermal metamorphism and metasomatism, and it is notable that extreme metasomatic effects leading to the formation of quasi-igneous rocks are particularly associated with "wet" magmas such as granite.

(b) *Mixing with Parent Magma.*

The progressive aggradation processes which take place under the influence of increasing energy and increasing supply of emanations (the progressive advance of the migmatite front of Wegmann (1936) could eventually lead to the formation, *in situ*, of rock types indistinguishable from "igneous" rocks, and in the present case certain sedimentary bands have, in fact, attained a grade which yields a mineral assemblage of igneous type. For example, the high grade hornfelses derived from poorly calcareous shales consist of biotite, hornblende, plagioclase, orthoclase, and quartz: they have the mineralogy of the quartz-diorite with the hornfels texture. Usually, however, owing to the increase in the quantity of pore-fluid and the resulting spongy character of the metasomatized rocks, the aqueo-siliceous melt (the parent-magma) was itself able to advance before the completion of the metasomatism process. Adjustment in equilibrium then took place under the new physico-chemical conditions between the solid phases and the parent-magma.

That part of granitization involving the mechanical and chemical effects of magma on solid material, particularly in the form of xenoliths, has been described by many workers. The changes concerned are covered by the term "reciprocal reaction" originally employed by Read (1923, p. 483). Bowen (1928, pp. 175–223) discusses, in the light of experimental evidence, the kind of reactions which would be expected to occur. The solid material is also subject to "mechanical disintegration" by marginal attack by the magma and the growth of porphyroblasts (see Nockolds, 1933, pp. 584–9) which leads to its dispersal through the magma.

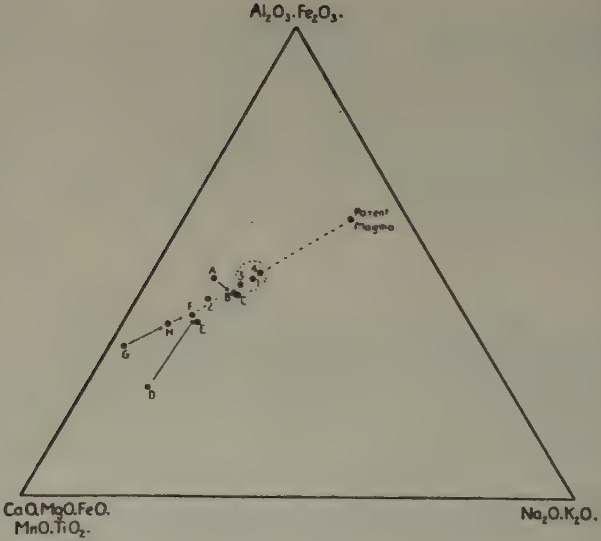
In the rocks being considered the effect of the process of mixing with parent magma is represented by an easily recognizable zone of mobilization. This, however, is not a clean cut line because certain hornfels bands were more easily mobilized than others and intrusion breccias sometimes resulted.



Text-fig. 2.—Plotting of the analyses on the basis of the norms, showing lines of Convergent Metasomatism and the line (broken) representing Mechanical Mixing of parent-magma with metasomatized hornfelses to form quartz-diorite. A, B, and C, poorly calcareous shale hornfelses (Table I). D, E, and F, greywacke hornfelses (Table II). G and H, calcareous shale hornfelses (Table III). 1, marginal quartz-diorite of poorly calcareous shale hornfels parentage (see MacGregor, 1937, p. 474, Anal. 14). 2, marginal quartz-diorite of greywacke parentage (see Table V). 3 and 4, normal quartz-diorites (see MacGregor, 1937, p. 459, Anals. 4 and 5).

On the inner side of the zone of mobilization fine-grained quartz-diorite types occur. Under the microscope these types still betray their hornfels parentage by their textures and mineralogy: relict hornfels inclusions are common, and some varieties contain diopside derived from calcareous shale or greywacke hornfels. The rocks as traced away from the margin lose these relict features, attain a coarser grain, and become, sometimes within a few yards, sometimes over a distance of a quarter of a mile, the typical quartz-diorite of the area. The field and microscopic details of the rocks which show the transition between high-grade hornfels and quartz-diorite have already been described (MacGregor, 1937, pp. 471–6).

The analyses of two of the marginal quartz-diorites have been plotted in Text-figs 2 and 3. Point 1 represents a fine-grained quartz-diorite containing abundant hornfels patches (MacGregor, 1937, p. 472). It lies between points 3 and 4 representing normal quartz-diorites (MacGregor, 1937, pp. 462–4), despite the fact that texturally and mineralogically it still shows evidence of its hornfels parentage. This rock is a derivative of the less calcareous type of shale hornfels, but its point on the diagrams does not lie directly on the continuation of the line representing the metasomatism of that type of sediment, but is shifted laterally owing to mechanical introduction of parent-magma.



Text-fig. 3.—Plotting of the analyses on an oxide basis. See Text-fig. 2 for explanation.

Point 2 represents a diopside-bearing fine-grained quartz-diorite of calc-greywacke derivation (MacGregor, 1937, p. 475), whose analysis is given in Table V. This lies between the high-grade calcareous hornfelses and the normal quartz-diorites.

The analytical evidence thus confirms the field and microscope evidence that the marginal quartz-dioritic types were evolved by he mixing of hornfels material, already partly granitized metasoma-ically, with the parent-magma. If this is true for the marginal ypes, it is only reasonable, as previously discussed (MacGregor, 937, pp. 476–7), to infer that the main mass of the quartz-diorite f the area was formed in the same way. In the case of the latter nechanical mixing has been more complete than in the marginal acies, and the mineral phases which were largely of hornfelsic origin nave approached more nearly to equilibrium with the magma luid. The quartz-diorite is considered, therefore, to represent the inal consolidated product of the granitization of the country-rocks.

(c) *The Parent-magma.*

It follows from the theory outlined above that the rising parent-nagma, which was responsible for the granitization process, was lominantly interstitial in nature. Hence it would only occur as an ndividual rock type in the field if squeezed out from the mush

TABLE V.

Analysis.		*Norm.*	
SiO_2	58·62	Qtz.	9·18
Al_2O_3	16·86	Or.	15·57
Fe_2O_3	0·08	Ab.	22·01
FeO	6·81	An.	25·30
MgO	5·43	Cor.	0·41
CaO	5·35	Hyp.	11·35
Na_2O	2·64	Enst.	13·60
K_2O	2·62	Ap.	0·34
H_2O +	0·22	Il.	1·22
H_2O −	0·97	Mt.	0·23
CO_2	*nil*	H_2O	1·19
TiO_2	0·61		100·40
MnO	0·07		
P_2O_5	0·14		
	100·42		
S.G.	2·79		

Fine-grained diopside-quartz-diorite (855). Low Bengairn, Auchencairn, irkcudbrightshire.
Analyst: alkalis by Geochemical Laboratories, rest by W. H. Herdsman.

crystals and injected in the form of a fissure infilling. It may be presented among the dykes described by King (1937) from the ea lying to the west of the quartz-diorite outcrop, some of which pproximate to the composition of the parent-magma deduced low. However, when selecting any particular rock type as presenting the original parent-magma, it must be remembered at the latter would have been continually changing its composition ving to reaction with foreign material; its composition would vary th from place to place and with time. Hence it is probably safer deduce a parent-magma composition for any particular case of granitization from a comparison of the country-rocks and the "mixed"-rock derived from them.

In Table VI the losses and gains suffered by the high-grade metasomatized country-rocks during their conversion to quartz-diorite are shown in grams per 100 c.c. As the three main types of high-grade hornfels occur in roughly equal proportion in the field, an approximation to their average composition has been computed from analyses C, F, and H; likewise an average of the two analyses of homogeneous quartz-diorite have been taken. The analyses of the marginal quartz-diorites cannot be employed safely in this connection as they bear traces of the particular type of hornfels from which they were derived.

The table shows a notable increment of Na_2O to the hornfelses during the conversion, little change in K_2O, an increase in Al_2O_3, and a decrease in SiO_2. CaO, FeO, and MgO decrease and Fe_2O_3 and P_2O_5 increase. Only a small volume increase is indicated which suggests that the amount of magma admixed with the hornfels material was small. This slight increase in volume, however, is probably one of the factors leading to movement between the mobilized mass and the walls.

An approximation of the limiting composition of the parent-magma can be obtained by contrasting graphically the average high-grade hornfels with the average quartz-diorite. The result is as follows:—

SiO_2	59·2
Al_2O_3	20·7
Fe_2O_3	2·6
FeO MgO	3·8
CaO	—
Na_2O	8·7
K_2O	3·3
MnO	0·1
TiO_2	0·2
P_2O_5	1·4
	100·0

which is equivalent to

Or.	19·5
Ab.	73·4
and	
Al_2O_3	2·8
Fe_2O_3	2·6
FeO MgO	3·8
MnO	0·1
TiO_2	0·2
P_2O_5	1·4
	103·8
$-$ SiO_2	3·8
	100·0

The use of different proportions of the quartz-diorites or of the hornfelses in calculating the averages leads to slightly differing results, which may show a small variation in the Na_2O/K_2O ratio, eliminate the FeO and MgO content, or bring in a little CaO. Nevertheless the calculated magma has always just about the correct quantity of SiO_2 to make felspar. It is also found that Al_2O_3 is always present in small excess, Na_2O preponderates over K_2O, and Fe_2O_3 and P_2O_5 are present in relatively large amount.

It is realized that a calculation of this kind is open to objection, but it does at least suggest that the parent-magma was soda-syenitic in character. Furthermore such a magma could supply the emanations which metasomatized the country-rocks.

The origin of such an alkali-felspar magma is a subject for speculation and is part of the wider problem of the origin of the granitic rocks in general. The writer favours the views of Eskola (1932), who visualizes the formation of felspathic fluid by a process of selective fusion at depth.

TABLE VI.

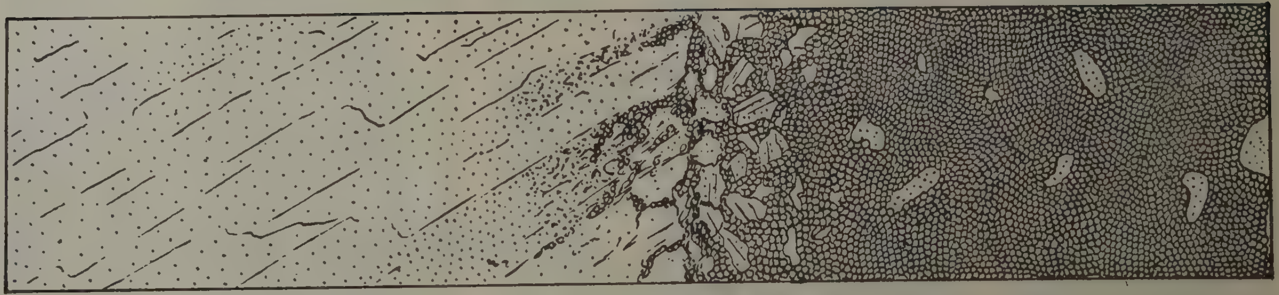
	Average High-grade Hornfels Grams per 100 c.c.	Average Quartz-diorite Grams per 100 c.c.	Difference Grams per 100 c.c.
SiO_2 . .	176·8	165·9	− 10·9
Al_2O_3 . .	37·6	42·6	+ 5·0
Fe_2O_3 . .	4·1	5·0	+ 0·9
FeO . .	14·3	10·0	− 4·3
MgO . .	11·6	10·1	− 1·5
CaO . .	22·7	14·4	− 8·3
Na_2O . .	5·8	11·1	+ 5·3
K_2O . .	7·6	7·9	+ 0·3
H_2O + .	2·9	2·3	− 0·6
H_2O − .	0·7	0·4	− 0·3
CO_2 . .	0·0	0·2	+ 0·2
TiO_2 . .	2·3	2·0	− 0·3
MnO . .	0·3	0·2	− 0·1
P_2O_5 . .	0·5	1·9	+ 1·4
	287·2	274·0	− 13·2

The position of the deduced magma is plotted in Text-figs. 2 and 3 and it forms the end of the line representing the process of mixing of the metasomatized hornfelses with parent-magma to form the "mixed" magma which consolidated as quartz-diorite. It should be noted that this line is independent of the lines representing metasomatism, which is further evidence for the view that the latter process is not due to penetration of the country-rocks by the parent-magma as such but is a selective inbibition of material in advance of the parent-magma front.

III. Summary and Conclusion.

The geochemistry of a process of "granitization" whereby greywackes and shales have been converted to quartz-diorite at the western end of the Criffell-Dalbeattie igneous complex indicates

TEXT-FIG. 4.



Conditions: Hydrothermal (Pneumatolytic).
Aggradation of mineral assemblages under influence of rising temperature and by reaction with pore liquid augmented by magmatic emanations.

Conditions: Magmatic.
Introduction of aqueo-siliceous parent-magma. Mobilization of the whole mass. Mechanical disintegration and strewing of country rock material. Reaction with parent-magma. Homogeneous " mixed magma " as final product.

Fluid (pore or parent magma) shown black. Country rock (unaltered, hornfels, and xenolithic) shown white.

that the process was due to the uprise of a "parent-magma" of alkali felspar composition.

As the magma rose it was preceded by an advance guard of hydrous solutions which carried chiefly alkalis and alumina. The solutions migrated through the pores of the country-rocks and chemical reactions between the solid phases of the rocks and the pore fluid were initiated. These reactions tended towards the local achievement of equilibrium at each stage of energy aggradation. Serial analyses of rocks across the aureole towards the quartz-diorite show that the changes were such as to cause divergent heterogeneous types of sediment to converge towards the bulk composition (and mineralogy) of a common end-product—the quartz-diorite. The process involved, therefore, selective metasomatism of the country-rocks.

Before granitization by metasomatism was carried to completion, the aqueo-siliceous parent-magma itself advanced and, mixing mechanically with the high-grade hornfels material, rendered the whole mass mobile. In contact with the parent-magma, and therefore under new physico-chemical conditions, the solid hornfels material was further modified by reciprocal reaction, and was mechanically disintegrated and strewed through the mass, so that eventually a homogeneous "mixed" magma resulted. Text-fig. 4 represents diagrammatically the conditions across the margin at any time when the energy level was rising.

Granitization is essentially the result of continuous readjustment of the mineral composition of rock under changing physico-chemical conditions. The two processes described, (1) metasomatism under the influence of hydrous pore solutions augmented by magmatic emanations and (2) mechanical mixing and reaction with aqueo-siliceous melt, vary in importance under different conditions. At one extreme quasi-igneous rocks may result by the metasomatic replacement of pre-existing rock, *in situ*, and at the other extreme magma emplacement may be mechanical with little or no reaction. In the case described metasomatism brought the composition of the country-rocks nearly to the composition of the quartz-diorite before mechanical mixing with parent-magma started. The amount of introduced magma was small, and there was little movement between the quartz-diorite "mixed" magma and its walls: clean intrusive contacts are absent. The quartz-diorite was thus formed almost in place. In the case of the granodiorites of the same igneous complex, metasomatism of the country-rocks was relatively slight and the margins are comparatively clean cut. Here the intruded material, already of granodiorite composition, was apparently emplaced mechanically at the level now exposed.

In conclusion the author wishes to record his thanks to Professor A. Brammall and Dr. Gilbert Wilson for many helpful criticisms and suggestions. The rocks alluded to in this paper are housed in the Geology Department, University College, London.

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The Status of Hornblende in Low Grade Metamorphic Zones of Green Schists.

By C. E. TILLEY.

THE detailed studies on rocks of the prasinite-green schist facies published during the last decade have thrown a flood of light on the genetic relations of the various members of this facies group. References may be made to the work of Vogt at Sulitelma (1),[1] Fischer in the Wippra metamorphic zone (2), Weg's studies in the Saxon *Zwischengebirge* (3), Turner's contributions on the Otago schists (4), and finally in this country to Wiseman's study of the progressive metamorphism of the Dalradian epidiorites (5).

The status of such minerals as amphibole and chlorite in the lower grade assemblages has naturally been the subject of discussion and considerable agreement has been reached in regard to the genetic relations of these minerals, though in view of the paucity of data available on the chemical composition of these phases which bulk largely in the constitution of the assemblages, there remains much yet to be elucidated.

In Britain two rock groups—the Green Beds of the Highlands (6) and the Green Schists of the Start area of South Devon (7)—form members of this facies group of contrasted origin, the former sedimentary and the latter genuine derivatives of basic igneous rocks. Both these rock groups have received petrographic study but I propose in the following account to devote some attention to special problems of their metamorphism in the light of more recent study and the results accruing from investigations in other areas.

PROBLEM OF HORNBLENDE-BEARING GREEN BEDS OF LOW METAMORPHIC ZONES.

Green Beds of the Dalradian sequence containing amphibole in low-grade metamorphic zones (chlorite zone of pelitic assemblages) were first recognized from single specimens from the mass of Creag nan Gabhar, south of Loch Earn (1 in. sheet Scotland 45) and within the Ben Ledi grits at Loch Boltachan, 1 mile north of St. Fillans, Loch Earn. A brief discussion of these rocks has since been made by Phillips (6, p. 239) in his paper on the metamorphism of the Green Beds. More recently a large series of Green Beds has been collected by Wiseman during his investigation of the Dalradian epidiorites. These have been incorporated in the petrological collections at Cambridge and are utilized in the present study.

Study of this enlarged collection of Green Beds of the original locality of Creag nan Gabhar shows that hornblende is a characteristic mineral of the assemblages. Hornblende occurs also in the Green Beds of the mass outcropping on the west side of Loch Lubnaig, north of Ben Ledi and farther south-west in 1 in. sheet 38 in the bands of Green Beds at the foot of Loch Katrine.

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[1] The numbers in parentheses refer to References at end of article.

In the original rocks to which reference was made, hornblende occurred in fine needles distributed in the ground, but in those now to be described hornblende occurs not only in this manner but also as large grains reaching up to ¾–1 mm. in diameter, sufficiently large to be recognized as black grains in the hand specimen interspersed with coarse detrital grains of quartz and albitic felspar.

The chief characteristic of these amphiboles as seen in thin sections is their zoned development—usually a brownish green core being surrounded by a colourless to pale green shell. These cores are often rounded but straight edges are not infrequent, and though clearly of contrasted composition both core and shell have typically a common extinction angle.

In a number of examples studied the refraction of the brown-green core has β 1·670 with an almost colourless shell β 1·642, $c \wedge \gamma = 20°$ for both. The associated chlorite of the rock containing them has β 1·627. The pleochroism of the cores is γ green, β brown-green, α greenish brown with some variation, γ tending to be more greenish, β more brownish and α light yellow-brown or yellow-green $\beta > \gamma > \alpha$.

Other distinguishing features of these zoned amphiboles in the Green Beds serving to indicate that a discontinuity existed during their development are :—

(*a*) Cleavage cracks may cease abruptly at the boundary of core and shell.

(*b*) A parting parallel to (100) may be present in the core but undeveloped in the shell. Parting parallel to (001) (reminiscent of salite structure in pyroxene) occasionally occurs in the core.

(*c*) Inclusions within the core include opaque iron ores while in the shell the enclosures are characteristically granular epidote which is not recorded for certain in the core.

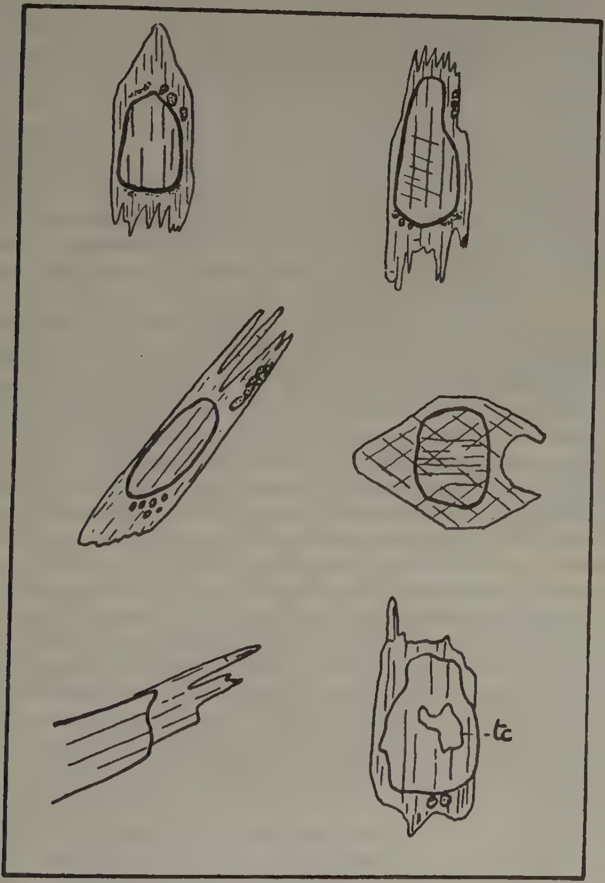
(*d*) The shell may extend in the form of outgrowths of thin fibres into the surrounding groundmass, these extensions then resembling optically the fine hornblende in the base.

Some of these features are brought out in the sections illustrated in Text-fig. 1.

There can be little doubt that these large hornblendes represent detrital grains which have during the metamorphism been enlarged and developed outgrowths with hornblende substance of different composition, and approaching actinolite.

The commonly rounded character of the cores might suggest that the clastic grains were composed wholly of the brown-green hornblende and that the pale green to colourless shells were developed *in situ*, but it appears possible that some of the clastic hornblendes were themselves composite. Those that now show idioblastic outline have completed their growth *in situ*. The new material added to the original grains is always very light coloured and as mentioned above appears to correspond optically to the fine hornblende of the outgrowths and that in the interspaces between the detrital quartz and albite grains.

Enlargement of clastic amphiboles in sediments involved in low grade metamorphism has been previously observed. Among the earliest observations are those of Van Hise (8, p. 231) who has recorded from Precambrian conglomerates of Minnesota enlargement of clastic hornblendes displaying features very similar to those of the Creag nan Gabhar examples. More recently Turner (4, p. 334) has



EXT-FIG. 1.—Clastic amphiboles with outgrowths of colourless to pale green hornblende, tc = talc. Green Beds, Creag nan Gabhar, south of Loch Earn, Perthshire. × 50.

described the building up of continuous pale borders to detrital coloured hornblendes from the lowly metamorphosed greywackes of the Te Anau Series of New Zealand.

Clastic amphiboles (together with clastic sphene, epidote, etc.) are reported from the epidotic grits of the Torridonian of Colonsay (9, p. 13)—particularly the Milbuie and Dun Gallain horizons. In zones of special shearing the Survey Officers note the development of abundant secondary hornblende. Whether this amphibole represents recrystallized amphibole substance of the epidotic grits or is generated independently from chlorite and calcite owing to local rise of temperature in the shear zones is not yet made clear.

The recognition of abundant clastic amphibole in the Green Beds of Loch Earn may be regarded as added support to the general belief that these rocks have been derived in part from the disintegration of basic rocks of igneous origin. Phillips's analysis of a hornblende type from Loch Boltachan (6, p. 254) indicates the close chemical similarity to basic igneous rocks possessed by some of them.

In many of the coarse grained examples of Creag nan Gabhar the interstitial material between the large albite and quartz grains is composed essentially of fine epidote and hornblende. This interstitial material may assume larger proportions in the form of dark slivers composed of the same minerals and representing a reconstituted basic mud. The large clastic albites are characterized by a turbidity due to fine gas inclusions and the common presence of multiple albite and pericline twinning. In these respects they contrast strongly with the recrystallized albites of metamorphic rocks. They show indeed a striking resemblance to the albites which form so prominent a constituent of the spilites, spilitic tuffs and breccias of the Tayvallich beds of the Loch na Cille district. The clastic hornblendes, however, have no counterpart in the Tayvallich lava series—at least those of the Tayvallich peninsula where amphiboles are relatively scarce except in recognized intrusive sills.

In the normal type of Green Bed of the chlorite zone—composed of chlorite, epidote and albite (± green biotite)—the appearance of amphibole appears to be delayed till close to the edge of the garnet zone (of pelites). This is exemplified in the Cowal district. The chlorites of the low zones in the Green Beds are typically green varieties predominantly optically positive with very low birefringence. Amphibole when it appears is associated with chlorite and is perhaps derived from it by reaction with epidote and calcite. These early amphiboles are often rather strongly coloured in green to bluish green tints—certainly more strongly coloured than the hornblendes in low zones in epidiorites of the Highlands. No analyses are available of any of these early amphiboles of the garnet zone but it would appear from their mode of origin that they may contain significant alumina.

In discussing the late appearance of amphibole in rocks of Green

Bed type, it was suggested that the presence or absence of sericite in the original sediment was of importance (7, p. 201), the formation of amphibole being possibly delayed in the presence of potash with the alternative formation of biotite. Later Vogt (1, p. 440) in comparing the development of amphibole in his retrograde series of metamorphosed basic igneous rocks (amphibolite → green schist) with that in the associated sedimentary series similarly expressed the view that compositional differences accounted for the late appearance of amphibole in the latter. He expressed this relation by an equation

$$\text{chlorite} + \text{actinolite} + \text{quartz} + K_2O \rightarrow \text{epidote} + \text{biotite}.$$

In other words the presence of K_2O inhibited the formation of amphibole in favour of that of biotite, with consequent delay of amphibole development to higher grades.

Now I am not clear that is the real reason why hornblende is delayed in the progressive metamorphism of sediments of the type of the Green Beds. There are in Cowal in the chlorite and biotite zones, Green Beds composed of chlorite-epidote calcite quartz and albite without the assumed inhibitor—a potash mineral. The hornblendic rocks of Creag nan Gabhar have been recognized as exceptional types but the reason for their unusual mineralogy seems now clear—to be traced to the presence of relict minerals in the form of hornblende and hornblendic (perhaps also originally pyroxenic) detritus which has recrystallized as actinolite in the groundmass, the larger clastic grains of amphibole at the same time developing outgrowths penetrating their environment.

GREEN SCHISTS OF THE START AREA, SOUTH DEVON.

These hornblendic rocks derived directly from basic igneous rocks (7) associated as they are with pelitic rocks of the chlorite zone present problems common to those of the Green Beds just described. These assemblages will be discussed in the light of the relations referred to and the new data now available on the Dalradian epidiorites (5).

The chief mineral assemblages of the green schists of the Start area comprise the following :—

$$\left.\begin{array}{l} \text{1. Hornblende-epidote-albite} \\ \text{2. Hornblende-chlorite-epidote-albite} \\ \text{3. (a) Chlorite-epidote-albite} \\ \quad\ \text{(b) Chlorite-epidote} \\ \quad\ \text{(c) Chlorite-albite} \end{array}\right\} \text{Sphene.}$$

Calcite is sporadically distributed but is more common in assemblages 2 and 3, i.e. with chlorite ± hornblende. Assemblages of type 3 usually contain traces of amphibole, indeed chlorite-epidote-albite assemblages completely devoid of amphibole are much less common.

An uncommon assemblage analysed by Kennedy and Dixon (10, p. 280) from Limebury Point, Salcombe Estuary is

4. Hornblende-talc-chlorite schist.

Of these types each is represented by an analysis (Table 6, 1–5).

Before considering the genetic relations of these assemblages the nature of the constituent chlorites and amphiboles will be discussed. In my previous paper (7) on the Start schists, analyses of two assemblages were made available, but no chemical data on the constituent minerals was supplied. For further discussion it is imperative that analytical data on these important phases should be available. This account now adds three analyses of amphiboles and one analysis of chlorite from the various assemblages.

CHLORITES OF THE START GREEN SCHISTS.

The pale green chlorites of the Start green schists are characteristically optically positive types having commonly a mean refractive index 1·617–1·620. Optically negative varieties are not common. When these occur they are characteristically more strongly coloured, due no doubt to larger iron content.

The relationship between the mean refringences of the chlorites and associated amphiboles disclosed by Wiseman (5) in the Dalradian epidiorites is found also in the Start rocks—the refraction of the chlorites rising with that of the associated amphibole, e.g. :—

β chlorite.	*sign.*	*β amphibole.*
1·600	+	1·627
1·605	+	1·629
1·611	+	1·633
1·620	+	1·638
1·632	—	1·650

The low β figures 1·600–1·605 for chlorites are from more magnesia rich amphibole-talc-chlorite rocks from Limebury Pt, Salcombe Estuary. The optical properties of the chlorites denote them as members of the prochlorite type (cf. Orcel (11)) rich in alumina.

As there are no analyses available of groundmass chlorites of rocks of the type of the Start schists, confirmation of their character is desirable. For this purpose an analysis of a chlorite separated from a chlorite-epidote-albite schist containing only traces of amphibole has been carried out and is set down in Table 1. The analysis is that of a typical prochlorite and it conforms closely to the accepted structural formula $(OH)_8Y_6(SiAl)_4O_{10}$ of the chlorite minerals.

Chlorites, optically positive and of prochlorite character, seem indeed to be characteristic of other green schist regions, e.g. of the Dalradian epidiorites and the green schists of Sulitelma (Norway). This similarity is indicated in Table 2 where the *estimated* compositions of chlorites from green schists of these areas are compared with the analysed Start prochlorite. The chlorites of the greenstones of the Saxon "*Zwischengebirge*" (Hainichen-Berbersdorf district) described

TABLE 1

	1	Metal atoms to 18 (O, OH)		
SiO_2 .	26·45	2·756		4·00
Al_2O_3	20·88	2·562	1·235	
			1·327	6·04
TiO_2 .	tr			
Fe_2O_3.	2·82	0·225		
FeO .	21·06	1·825		
MnO .	0·44	0·037		
MgO .	16·84	2·631		
CaO .	0·16			
Na_2O .	0·12			
K_2O .	0·19			
H_2O —	0·11			
H_2O +	10·98	7·625		7·62
	100·05	$(OH)_{7.6})Mg, Fe, Al)_6(Si, Al)_4O_{10}$		
Sp. Gr.	2·950	α 1·619, γ 1·623 2V small + X, Y very pale green Z colourless to very pale yellow		

1. Chlorite (prochlorite) from chlorite - epidote - albite schist, Limebury Point, Salcombe Estuary, South Devon. Analyst, H. C. G. Vincent.

by Weg (3, p. 71) are mostly optically negative (β 1·620–1·640) and while aluminous they would appear to be more iron rich than the prochlorites referred to above.

TABLE 2.

	1	2	3	4	5
SiO_2 .	26·45	25·8	28·2	25·2	25·7
Al_2O_3 .	20·88	20·8	24·9	23·4	22·2
TiO_2 .	tr	0·8	—	—	—
Fe_2O_3 .	2·82	—	0·2	2·2	4·4
FeO .	21·06	21·0	26·8	16·9	13·7
MnO .	0·44	0·4	—	0·1	0·3
MgO .	16·84	18·6	10·9	20·6	22·5
CaO .	0·16	0·4	—	—	—
Na_2O .	0·12	0·6	—	—	—
K_2O .	0·19	0·3	—	—	—
H_2O —	0·11	11·3	9·0	11·6	11·2
H_2O +	10·98				
	100·05	100·0	100·0	100·0	100·0

1. Prochlorite, Limebury Pt., Salcombe Estuary (see Table 1).
2–5. Calculated composition of chlorites from
2. Chlorite-epidote-albite schist, Dragset, Trondhjem district, Norway. C. W. Carstens (12, p. 203).
3. Chlorite-albite-schist, Eilean Traighe, west of Tayvallich, Argyllshire. J. D. H. Wiseman (5, p. 362).
4. Chlorite-albite fels from area above Furuland, Sulitelma, Norway.
5. Chlorite-albite fels from Grönli, Sulitelma, Norway. Th. Vogt (1, p. 321).

Amphiboles of the Start Green Schists.

The characteristic amphiboles of the Start schists are pale grey-green weakly pleochroic varieties occurring commonly in long fibres with simple habit {110} as seen in cross sections. Less commonly the hornblende is partly developed as porphyroblasts ($1\frac{1}{2}$ mm. in diameter). Good examples have been described from the Signal Station at Prawle Point. Much less frequently the colour of the amphibole shows a distinct bluish green element in its absorption scheme (Z). In these cases the amphibole is more strikingly pleochroic. The best examples occur in the nodular epidotic segregations in the green schists south of Moor Sands, Prawle Coast. Here the amphibole may be accompanied by calcite and often a green biotite. These bluish green amphiboles occur with chlorites which are usually more deeply coloured than the usual types met with, and this association doubtless bespeaks a higher iron content both for the chlorite and the amphibole. In some cases the associated chlorite is an optically negative type.

No analyses of amphiboles of the typical Start green schist are as yet available and as reliance on the composition of amphiboles estimated from bulk analysis of the rocks is questionable, three analyses of isolated amphiboles have been carried out.

The first analysis (Table 3) has been conducted on the amphibole

TABLE 3.

	1	Metal atoms to 24 (O, OH).		
SiO_2 . .	54·33	7·743		8·00
Al_2O_3 .	2·68	0·450	0·257	
			0·193	4·98
TiO_2 . .	0·29	0·032		
Fe_2O_3. .	1·09	0·116		
FeO . .	11·68	1·393		
MnO . .	nil	—		
MgO . .	15·31	3·250		
CaO . .	12·46	1·901		2·07
Na_2O . .	0·54	0·149		
K_2O . .	0·12	0·022		
H_2O − .	0·20			
H_2O + .	2·04	1·94		1·94
	100·74			
Sp. Gr. .	3·11	α 1·627, β 1·641, γ 1·650 Z pale green, Y pale green, X pale yellow green. $Z \wedge c = 20°$.		

1. Hornblende from hornblende-epidote-albite schist below Signal Station, Prawle Point, Start District, South Devon. Analyst: H. C. G. Vincent.

isolated from a hornblende-albite-epidote schist of the same type as analysed (7, p. 186). In this rock the amphibole is partly present as porphyroblasts and is a typical pale amphibole of the green schists.

The second analysis is that of a very pale finely fibrous type from a hornblende-epidote (clinozoisite)-albite schist from Limebury Point. Its composition and optical properties are set down in Table 4.

Both the rocks from which these amphiboles have been isolated contain only a small amount of chlorite.

From rocks of the type now under consideration, i.e. containing epidote and an albitic felspar various authors have attempted calculations of the composition of the contained amphiboles from the bulk analysis of the rock and an estimated weight percentage of the constituent minerals. Reference may be made to the works of Väyrynen (15), Carstens (12), and Th. Vogt (1). Their results give alumina percentages of the amphiboles rising to 16·4 per cent: Väyrynen (11·3 per cent, 13·5 per cent), Carstens (8·4 per cent, 16·4 per cent), while Vogt tabulates a series of calculations of the composition of amphiboles of the green schists of the Sulitelma region—the alumina percentages ranging from 10·1 (in epidote-amphibolite free from chlorite) to nil (in chloritic greenstone with accessory amphibole). These calculations should of course not be taken too seriously as the errors arising from the assumptions made may be considerable, especially where the content of amphibole is low.

TABLE 4.

	1	Metal atoms to 24 (O, OH).	
SiO_2	54·73	7·734	7·98
Al_2O_3	1·46	0·244	
TiO_2	0·21	0·022	4·95
Fe_2O_3	nil	—	
FeO	9·60	1·135	
MnO	0·16	0·019	
MgO	17·94	3·779	
CaO	12·76	1·932	2·33
Na_2O	1·44	0·394	
K_2O	tr		
$H_2O -$	nil		
$H_2O +$	2·27	2·140	2·14
	100·57		
Sp. Gr.	3·09	α 1·617, β 1·630, $\gamma = 1·641$, Z ∧ c = 18°.	

1. Hornblende from fibrous hornblende-clinozoisite-albite schist, Limebury Point, Salcombe Estuary, South Devon. Analyst: H. C. G. Vincent.

An amphibole has been isolated from an assemblage of type 4, viz. amphibole-talc-chlorite schist. Its composition and optical properties are set down in Table 5. As already noted a rock of this

TABLE 5.

	1	Metal atoms on basis of 24 (O, OH).		
SiO_2 . .	54·78	7·591		8·00
Al_2O_3 .	3·67	0·598	0·409 0·189	5·08
TiO_2 . .	0·22	0·024		
Fe_2O_3. .	0·45	0·046		
FeO . .	7·38	0·855		
MnO . .	0·18	0·021		
MgO . .	19·10	3·943		
CaO . .	12·65	1·878		1·88
Na_2O .	nil			
K_2O . .	nil			
H_2O − .	0·09			
H_2O + .	2·39	2·210		2·21
	100·91			
Sp. Gr. .	3·06	α 1·618, β 1·629, γ 1·638 Z ∧ c = 17°.		

1. Hornblende from hornblende-talc-chlorite schist, Limebury Point, Salcombe Estuary, South Devon. Analyst: H. C. G. Vincent.

TABLE 6.

	a	b	c	d	x	y
SiO_2 .	54·33	51·60	50·54	54·73	54·78	44·56
Al_2O_3 .	2·68	2·35	4·32	1·46	3·67	9·57
TiO_2 .	0·29	0·50	1·70	0·21	0·22	0·56
Fe_2O_3 .	1·09	2·60	2·94	nil	0·45	0·54
FeO .	11·68	15·21	10·14	9·60	7·38	7·99
MnO .	nil	0·20	0·28	0·16	0·18	0·22
MgO .	15·31	12·91	14·02	17·94	19·10	22·37
CaO .	12·46	10·97	12·58	12·76	12·65	7·94
Na_2O .	0·54	0·91	0·80	1·44	nil	0·27
K_2O .	0·12	0·53	0·00	tr	nil	0·07
H_2O − .	0·20	?0·56	2·68	nil	0·09	0·27
H_2O + .	2·04	?2·05		2·27	2·39	5·51
	100·74	100·39	100·00	100·57	100·91	100·14

(a) Hornblende from hornblende-epidote-albite schist, Prawle Point, Start District (Table 3, analysis 1).

(b) Hornblende from epidiorite (chlorite-epidote-albite amphibolite), 0·4 miles S.E. of Loch Gair Hotel, Argyll. Wiseman (5, p. 368).

(c) Hornblende from albite-amphibole-epidote rock. Maaselkä, Aunus, Karelia. Eskola (13, p. 43).

(d) Hornblende from hornblende-clinozoisite-albite schist, Limebury Pt., Salcombe Estuary (Table 4, analysis 1).

(x) Hornblende from hornblende-talc-chlorite schist, Limebury Pt., Salcombe Estuary (Table 5, analysis 1).

(y) " Hydroamphibole " from amphibole-talc-chlorite schist, Limebury Pt., Salcombe Estuary, includes Cr_2O_3 0·14, NiO 0·13. Kennedy and Dixon (10, p. 284).

composition has been analysed by Kennedy and Dixon (cf. Table 7, No. 3). Though the rock comes close in bulk composition to some ultrabasic types its mode of occurrence in lenticular bands wedging out to thin films indicate it rather as a product of metamorphic migration as Kennedy and Dixon suggest. This assemblage is an uncommon type among the Start green schists, but further comment upon it is necessary as Kennedy and Dixon give the results of an analysis of the contained amphibole which they designate as " hydroamphibole "

TABLE 7.

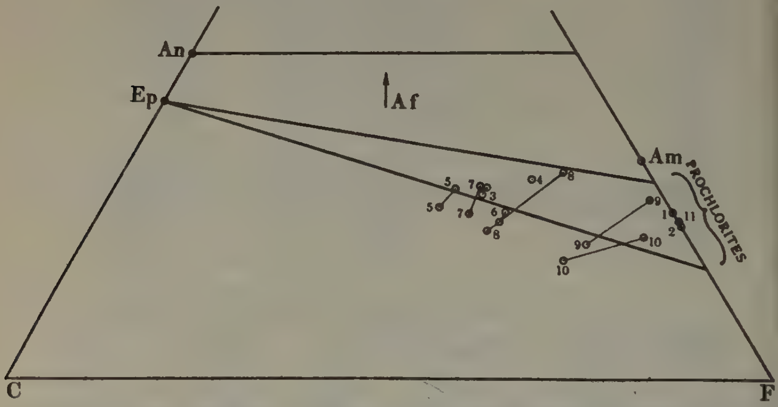
	1	2	3	4	5
SiO_2 . . .	48·60	35·89	44·77	49·32	47·86
Al_2O_3 . .	15·40	21·09	10·24	14·82	17·01
Fe_2O_3 . .	4·07	4·69	0·48	3·08	2·60
FeO . . .	7·47	10·32	8·82	7·27	6·05
MgO . . .	7·60	8·89	20·54	7·94	9·42
CaO . . .	8·34	10·32	7·99	11·25	9·56
Na_2O . .	3·18	0·70	0·25	2·54	2·84
K_2O . . .	0·50	0·06	0·37	0·32	0·17
H_2O − . .	0·38	0·24	0·15	0·13	0·25
H_2O + . .	3·31	5·41	5·12	2·26	2·75
TiO_2 . . .	1·77	1·53	0·93	1·55	1·05
P_2O_5 . . .	tr	0·10	—	—	0·05
MnO . . .	—	0·25	0·25	—	0·21
Accessories .	—	0·33	0·31	—	0·10
	100·62	99·82	100·22	100·48	99·92
Sp. Gr. . .	2·936	—	—	3·010	—

1. Hornblende-chlorite-epidote-albite schist, Seacombe Sands, Prawle Coast, South Devon (7, p. 183) (1, Text-fig. 3).
2. Chlorite-epidote-schist, Limebury Pt., Salcombe, includes C 0·29, Cr_2O_3 0·04 (14, p. 93). This rock contains, in addition to chlorite and epidote, minor amphibole, albite, quartz, and sphene.
3. Hornblende-talc-chlorite schist, Limebury Pt., Salcombe, includes Cr_2O_3 0·19, NiO 0·12 (10, p. 280) (6, Text-fig. 3).
4. Hornblende-epidote-albite schist, Signal Station, Prawle Pt. (7, p. 186) (2, Text-fig. 3).
5. Hornblende-chlorite-epidote-albite-schist, Limebury Pt., Salcombe, includes C 0·07, Cr_2O_3 0·03 (14, p. 93) (5, Text-fig. 3).

For permission to examine and refer to here the rocks analysed by Messrs. Dixon and Harvey (analyses 2, 3, 5 above), I am indebted to the Director of the Geological Survey and also to Dr. Kennedy from whom I have received helpful discussion on the problems presented by these assemblages.

with an alumina content of 9·57 per cent and H_2O above 105° of 5·51 per cent (Table 6, y). The two amphiboles come from identical assemblages and have almost identical properties, yet there is a marked discrepancy shown in their tabulated compositions. Furthermore the analysis of the rock (Table 7, No. 3) and the contained " hydroamphibole " (Table 6, y) are strikingly alike. In view of the difficulty of separating the amphibole in a pure state from talc and chlorite—a clean separation required the use of a high speed centrifuge—it would appear that the discrepancy is due in the case of the "hydroamphibole" to admixture with chlorite, whence the low lime, high alumina and water contents of the analysis. The amphibole of Table 5 corresponds closely with those of Tables 3 and 4 and offers no difficulty in structural interpretation.

The determination of the Start amphiboles as actinolitic in character and the chlorites as aluminous prochlorite enable us to compare more closely the two assemblages constituting (1) hornblende-epidote-albite schist and (2) chlorite-epidote-albite schists. No assemblage built up of epidote, prochlorite, and albite can have a like bulk composition to a rock composed of actinolitic hornblende, epidote, and albite. This is clearly seen from Text-figs. 2 and 3 showing the fields of the assemblages.



TEXT-FIG. 2.—Plot of analyses of chlorite-epidote-albite schists (3–10) giving the composition range of the chlorites of these green schists. Lower circles, the bulk analysis; upper circles, analyses after removal of CaO and TiO$_2$, equivalent to calcite and sphene present. 1, 2, chlorites (calculated) from albite-chlorite fels (Sulitelma). 11, analysed prochlorite (Analysis 1, Table 1).
[An = anorthite; Ep = epidote Am = amesite. AfCF projection.]

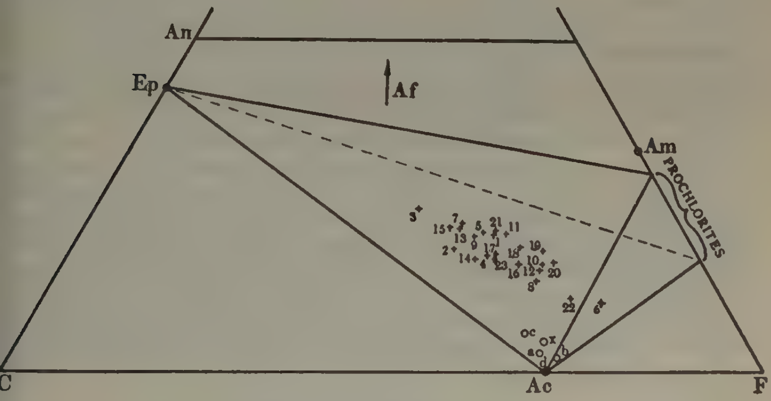
In Text-fig. 2 are plotted the compositions of chlorite-epidote-albite schists from various green schist areas—3 (Start), 4–8 (Switzerland), 9 (Tayvallich), 10 (Trondhjem). The upper circles (of the respective joins) represent the compositions after the extraction of CaO and TiO$_2$ equivalent to calcite and sphene in the mode. These projections thus give the compositions of epidote-chlorite mixtures and hence the composition range of the chlorites.

In Text-fig. 3 a group of hornblende-epidote-albite (oligoclase) schists, some with chlorite, are similarly plotted. The field lies as a whole below that of the previous field in accordance with the presence of abundant amphibole.

Between the extreme assemblages come the more abundant rocks in which actinolite and chlorite are associated in varying proportions. The chemical relations of the two types (as seen in the plots of Text-figs. 2 and 3) are of course consistent with their ultimate derivation from basic igneous rocks of basaltic composition.

Viewed in the light of their mineralogy this difference in bulk chemical composition is strongly suggestive that the chlorite rich assemblages have experienced a significant change in composition—notably a loss of lime—during their metamorphism, rather than that they had originally a different composition.

Apart from the presence of calcite in them, the restriction of amphibole as fine acicular enclosures within albite in rocks containing no trace of hornblende associated with the chlorite—in itself provides strong evidence that the enclosures represent residual amphibole protected within albite whereas all has disappeared from the chloritic aggregates.



Text-fig. 3.—Plot of analyses of hornblende-epidote-albite schists (1–22). Start area rocks (1, 2, 5, 6, analyses 1, 4, 5, 3 respectively of Table 7). Analysed amphiboles a, b, c, d, x (analyses of Table 6). [An = anorthite; Ep = epidote; Ac = actinolite; Am = amesite. AfCF projection.]

Now it is not to be inferred that all chlorite of these assemblages is to be traced to a hornblendic derivation. In the Dalradian epidiorites chlorite and hornblende have been shown to be products of the degradation of pyroxene, basic plagioclase supplying the necessary alumina for prochlorite, lime being released in the process. Assemblages built up of sharply idioblastic amphiboles associated with chlorite together with albite and epidote may thus have arisen directly from original pyroxene-bearing rocks. However, where chlorite is the dominant mineral of the assemblage there is often clear evidence that hornblende is disappearing. Rock types rich in chlorite but containing small amounts of amphibole isolated in chlorite or enclosing streaks of an amphibole rich assemblage appear intercalated in narrow zones between hornblende-epidote-albite schists, suggesting derivation from them. In the chlorite amphibole may appear as minute needles with frayed or embayed borders ultimately disappearing in the chlorite ground.

As mentioned above the last stronghold of such hornblende is the core of albite porphyroblasts. A transformation of this kind clearly involves loss of lime. Vogt (1) in discussing the development of his retrograde series, amphibolite ⟶ albite-chlorite-fels interprets the reactions developing the greenstone facies (from the actinolite greenstone facies) as involving a loss of CaO and SiO_2 and ultimately soda (in the removal of albite). At a higher stage the conversion of aluminous amphibole (epidote amphibolite facies) to actinolite the transformation is believed to take place without change of bulk composition by the simultaneous development of epidote ;

$$\text{Al. hornblende} + H_2O \longrightarrow \text{clinozoisite} \\ + \text{chlorite} + \text{actinolite} + \text{quartz.}$$

The Start rocks provide no evidence in favour of this reaction, the alumina of the chlorite (prochlorite) being regarded as derived largely from basic plagioclase or epidote (see below). In the Start rocks giving clear evidence of chlorite development at the expense of actinolite (of the actinolite epidote facies) the source of alumina can now no longer come from plagioclase. For this epidote remains the most likely source :—

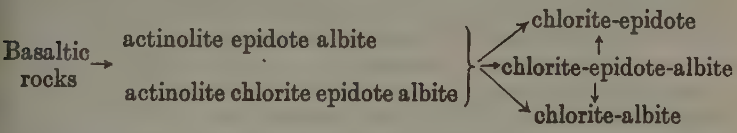
$$\text{actinolitic hornblende} + \text{epidote} \\ \longrightarrow \text{prochlorite} + SiO_2\nearrow + CaO\nearrow.$$

(CaO being removed or sometimes remaining as calcite). Such a reaction demands a reduction in the amount of epidote and evidence for this is not wanting.

One of the features of the chlorite-epidote-albite schists, however, is the variable amount and irregular development of epidote. Some areas are enriched in this constituent while others are deficient. The problem is thus complicated by the migratory character which epidote possesses. In this respect it resembles albite, both minerals tending at times to form nests, simulating amygdales in the green schists by segregatory action.

The reaction set forth above is, however, probably too simple a representation of the processes actually at work. We may take a concrete case provided by the two assemblages represented in analyses 2 and 5 of Table 7. These two rocks have a close field association, the hornblende-rich assemblage (analysis 5) appearing as a lenticle bordered by the chlorite epidote albite schist (analysis 2) in which some hornblende is still preserved in narrow streaks. In the derivation of the latter from the former there have been fundamental changes of composition. Clearly there has been an addition of water. The discrepancy in the soda values—in view of the proven migratory character of albite—suggests a notable removal of this constituent as albite. When this change is effected it is seen that the principal remaining adjustments are the removal of additional silica, lime, and magnesia. These constituents appear to be freed in the breakdown of amphibole ± epidote.

The development of the Start assemblages is summarily indicated in the following scheme :—



The freeing of lime and hence the development of chlorite rich assemblages appears thus dependent on the availability of $H_2O \pm CO_2$ solutions which may have operated both during the main metamorphism and the period of movement when the Start schists were brought into contact with the Devonian rocks lying to the north. Eskola and Turner have suggested that the various assemblages may be merely heterochemical associations of one mineral facies (in the chlorite zone). This is a view which the evidence of the Start schists does not preclude and which moreover receives support in the chlorite-epidote-albite-calcite assemblages of the Dalradian Green Beds in the higher parts of the chlorite zone.

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An Exploratory Boring in the Lower Carboniferous of the Skipton Anticline.

By R. G. S. Hudson, Department of Geology, The University, Leeds.

RECENT work on the succession and structure of the Skipton Anticline[1] has proved strata about 6,000 feet thick. These beds are of Dinantian age ranging from γ to P_2 and are in great contrast to the strata of the Askrigg massif, 8 miles to the north, where the Dinantian is of S_1 to P_2 age and is only 800 feet thick.

Near Skipton the γ–C_1 limestones are quarried by the Skipton Rock Co., Ltd., on both sides of Haw Bank, the feature formed by the core of the anticline. In 1937 this Company, in order to prove their reserves of limestone, commenced to bore near the crest of the anticline in approximately the lowest beds exposed. The bore started at 725 feet O.D. and was continued for 300 feet to 425 feet O.D. At this depth boring was discontinued since the rock had been proved to 70 feet below the floor of Haw Bank Quarry, below which it had no economic interest for the Skipton Rock Co. The core to this depth was examined by Dr. G. H. Mitchell, of the Geological Survey, and by the author. It proved 260 feet of calcareous mudstones with fine-grained argillaceous limestones, containing occasional zaphrentids. Below these beds the core was mainly argillaceous limestones with some mudstone. The dip in the strata of the core to 300 feet varied from 30 to 35° with a dip of 60 to 70° at 223 to 231 feet, probably due to the proximity of a fault. The beds to 300 feet were provisionally determined as of Z age.

It was realized that further continuation of the boring might prove the total thickness in the Craven basin of sedimentation of the Dinantian and even determine the nature and age of the strata below that formation. Grants to continue the boring were made by the British Association (Critical Sections Committee, Section C), by the Geological Society from the Gloyne Fund, by the Skipton Rock Co., Ltd., and, through the courtesy of Lord Cadman, by the D'Arcy Exploration Co., Ltd. The Skipton Rock Co., Ltd., also gave permission to continue the boring and provided both power and water. Thus, with the help of the boring company, Messrs. J. T. Hymas, and under the general supervision of Professor Fearnsides, the bore was continued to 700 feet (25 feet O.D.) at which depth, owing to mechanical difficulties and exhaustion of the various grants, it was discontinued.

The boring was by chilled shot rotary coring. No casing was used and a complete 4½ inch core was usually obtained. Much assistance was given in the recording and collection of fossils by

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[1] Hudson, R. G. S., and Mitchell, G. H., 1937, *Summ. Prog. Geol. Surv. for 1935*, pt. ii, pp. 1–45.

Dr. G. H. Mitchell and students of the Geological Department of the University of Leeds. As the final faunal analysis and lithological account will not be completed for some time, the preliminary results, based on field evidence, are stated here.

The dip of the beds in the upper part of the bore, 0–300 feet, was generally about 30 to 35°. Below this the dip rapidly decreased to horizontal, remaining so to 510 feet. Then there was a rapid increase to 70 to 80° at 570 feet, after which there was a slow decrease to the 30° dip in the beds at the base of the bore. This change from moderately dipping to horizontal and then to steeply dipping strata may be most simply explained by the supposition that the axial plane of the anticline is not vertical and that the bore, starting on one flank of the anticline, passed through the crest between 360 and 500 feet and then entered beds on the opposite flank.

The approximate true thickness of the various divisions has been calculated from the dip shown by the cores and from the depth in the boring.

Calculated Thickness.	*Rock-type.*	*Zone.*	*Depth in bore.*
	Bearing	—	to 6 ft. 6 in.
184 ft.	"Micaceous", calcareous mudstones with argillaceous limestones. Occasional brachiopods and zaphrentids. *Syringopora* common in upper beds. Foraminiferal limestone at 130 ft.	Z	to 206 ft.
86 ft.	Argillaceous limestones and calcareous mudstones. Occasional shell and crinoid debris. Turbulent bedding common	?Z	to 305 ft.
66 ft.	Bryozoan beds. Calcareous mudstones with thin limestones. Considerable shell and crinoid debris with *Fenestella* and other bryozoa. Occasional productids and algal fragments	—	to 372 ft.
94 ft.	Silty micaceous mudstones with thin limestones. Rare lamellibranchs and plants. Fish scales and teeth	Km	to 466 ft.
23 ft.	Shelly fragmental and crinoidal limestones with some mudstone. *a* limestones at top. Abundant ostracods with productids, spiriferids, and bryozoa	K	to 489 ft.
60 ft.	Mainly silty mudstones with abundant "fucoids", "worm-casts", and phosphatic nodules. Occasional carbonaceous or pyritous plant debris. Near top shelly *a* limestones and ostracod limestones	K	to 569 ft.
8 ft.	Grey fragmental shelly and crinoidal limestones	K	to 587 ft.
11 ft.	Unfossiliferous laminated mudstone and limestone. Small scale current and turbulent slip-bedding	—	to 606 ft.
10 ft.	Argillaceous limestones with abundant quartz grains. Coarse fragmental and crinoidal shell-breccias with algal debris, spiriferids and ostracods	K	to 619 ft.

Calculated Thickness.	*Rock-type*	*Zone.*	*Depth in bore.*
16 ft.	Unfossiliferous sandy micaceous mudstones with limey bands. Occasional phosphatic nodules. Turbulent bedding . . .	—	to 643 ft.
43 ft.	Compact level-bedded non-calcareous mudstones with occasional thin beds of quartzose siltstone. Abundant modioliform lamellibranchs	—	to 700 ft.

The allocation of the upper beds (0–206 feet) of the boring to the zone Z is based on the occurrence of various zaphrentids. The Bryozoa beds below contain a fauna of calcareous shale phase and, occurring between beds of undoubted Z and K age, are referred to the passage zone β. The rare fossils in the silty mudstones from 372 to 466 feet suggest a fauna of *Modiola* phase. The shelly limestones and mudstones between 466 and 587 feet contain abundant productids, spiriferids, and chonetids. These faunas are comparable to those of the Lower Limestone Shales of K age in the south of the British Isles and also to those of the Assise d'Etroeungt of Strunian age in Belgium and France.

The Z beds are assigned to the base of the Tournaisian. The beds of K age, following recent practice, [1] [2] [3] are grouped as the upper part of the Famennien (Devonian), and included in the *Wocklumeria zone.*

The thickness of non-calcareous lamellibranch mudstones at the base of the bore are of considerable interest. The fauna is of *Modiola* phase and resembles that of the Devonian beds of South Wales listed by Dixon.[4] It is possible that they are at or near the base of the marine deposits of the Craven Lowlands and that further boring would have passed into non-marine Devonian or the rocks of the pre-Upper Palaeozoic floor.

The lithology of the rocks throughout the boring is remarkably similar to that of those beds of the same age (Z and K) described from the South-West Province [4] [5] [6] and from Southern Ireland.[7] It seems likely that these districts and the Craven Lowlands were part of one area of sedimentation in Z and K times and that the absence of these beds from the area connecting the Mercian Highlands and St. George's Land is due to subsequent erosion and not to non-deposition.

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[1] Hudson, R. G. S., and Turner, J. S., 1933, *Proc. Leeds Phil. Soc. Sci., Sect.*, **ii**, 467.

[2] Paeckelmann, W., and Schindewolf, O. H., 1937, *Compte rendu du deuxième Congrès pour l'avancement des études de Stratigraphie Carbonifère*, Heerlen, 1935, **ii**, 703.

[3] Jongmans, W. S., and Gothan, W., 1937, *idem*, **i**, 4.

[4] Dixon, E. E. L., 1921, "Pembroke and Tenby," *Mem. Geol. Surv.*, Sheets 244 and 245, p. 48.

[5] Vaughan, A., 1905, *Quart. Journ. Geol. Soc.*, **lxi**, 251.

[6] Sibly, T. F., and Reynolds, S. H., 1937, *Quart. Journ. Geol. Soc.*, **xciii**, 23.

[7] Smyth, L. B., 1930, *Proc. Roy. Irish Acad.*, **xxxix**, B, 523.

Notes on the Geology of the Lizard Peninsula. No 3. The Epidote Bands, Lenticles, and Veins.

By J. B. Scrivenor.

A STRIKING feature of the geology of the Lizard is the occurrence of rocks very rich in, or consisting entirely of epidote ; as bands parallel to the foliation of the hornblende-gneiss and the green schists of the Old Lizard Head Series ; as lenticles caused by local enlargement of those bands ; and sometimes as veins cutting the foliation, for instance on Polurrian Beach. The coast-sections at Mullion do not show great development of these epidotic rocks in the hornblende-gneiss but bands one inch thick occur. At Porthallow and north of Porthoustock there is an even smaller development of these rocks, but along the coast from Pentreath Beach southwards round Lizard Point to Cadgwith epidote bands and lenticles are abundant. Sir John Flett remarks in the 1912 Memoir (p. 50) on the perfection of this banding, " which cannot be paralleled anywhere else in Britain," but he has told me that in Anglesey epidotic rocks approach them in abundance. These Anglesey rocks were described by Dr. E. Greenly in the Survey Memoir of that area (1919, pp. 108 and 109 *inter alia*).

In my second contribution on Lizard geology I concluded with some remarks on nomenclature. While preparing this contribution I found that as a comparison between the hornblende-schists and actinolite-schists (" green schists ") of the Old Lizard Head Series with the primary hornblende-schists and gneisses (" The Lizard Hornblende Schists " of the Memoir) is necessary, the use of the term " hornblende-schists " at all for the latter would result in confusion, so in this contribution, for the sake of clearness, " The Lizard Hornblende Schists " will be referred to as " hornblende-gneiss " only.

Text-fig. 1 shows the type outcrop of the Old Lizard Head Series and the extent of the outcrop of hornblende-gneiss in the Landewednack area. Dips in the Old Lizard Head Series and foliation-dips in the hornblende-gneiss are shown along the coast, also a number of names of headlands, etc. Regarding the latter, there is some doubt about the use of the names " Lizard Head " and " Lizard Point ". I have followed the present local usage for Lizard Head, which is a fine headland with an outline when viewed from the rocks near the Quadrant like a bewigged judge with a prominent nose. Immediately to the south is Little Lizard Head, and to the south again Canker Drang (Crab Channel) where one can descend by a rough path to the Wiltshire Rock. At Canker Drang the rocks are much folded and there is a conspicuous local dip in consequence to the E.N.E. (cf. Memoir, pp. 57 and 58).[1] On the face of Lizard Head is a wonderful

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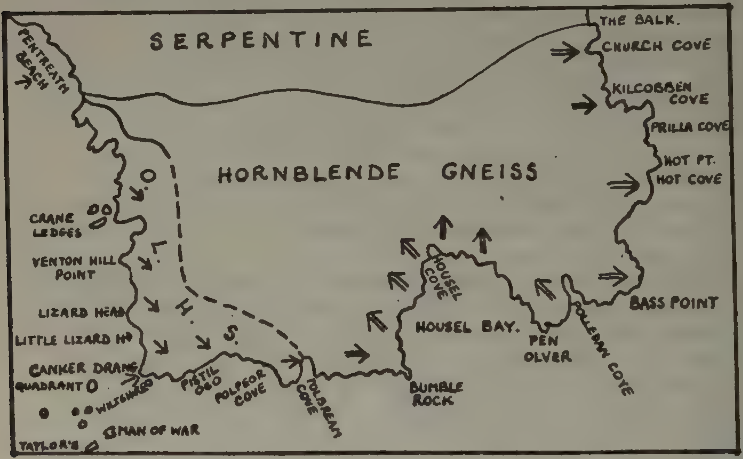
[1] See also Howard Fox on " The Gneissic Rocks off the Lizard ", *Quart. Journ. Geol. Soc.*, xliv, 1888, p. 309, and map opposite p. 316.

S-fold that can only be seen from the sea and does not figure in the Survey collection of photographs. On the six-inch Ordnance Survey map Canker Drang is called " Lizard Point ", but locally that name means the southern termination of the Lizard Peninsula from Canker Drang to the Bumble Rock including the dangerous reefs exposed at low tide off Polbream and Polpeor Coves. In the Memoir Lizard Head is called Old Lizard Head.

Starting from Pentreath Beach green schists are found along the coast to Polbream Cove, mostly lower down in the cliffs than the mica-schists and altered quartzites. In Polbream Cove the hornblende-gneiss begins. Up to the Bumble Rock there are not very many epidote bands and lenticles, but I found one lenticle near sea-level measuring 4 ft. by 6 in. The gneiss is fairly coarse and I noted a six-inch band in which porphyritic crystals of felspar are common. Near the Bumble Rock epidote bands and lenticles become more numerous and here I also found a very interesting occurrence of mica-schist while testing an idea based on the dips. In Polledan Cove, where a well-known inclusion of mica-schists occurs in the hornblende-gneiss, the general dip is N.W. The general dip of the Old Lizard Head Series is S.E. Reference to Text-fig. 1 will show that these dips might possibly indicate the previous existence of a syncline in the Old Lizard Head Series, invaded by the hornblende-gneiss, in which case the southern limb of the syncline should outcrop near the Bumble Rock. Careful search was rewarded by finding this mica-schist, which will be described later, and also a four-inch band of acicular hornblende-schist that may be an inclusion of " green schist ", but that is doubtful.



Text-fig. 1.—The coast from Pentreath Beach to The Balk. Scale 2 inches to 1 mile.

In Housel Cove epidote bands and lenticles are common but not conspicuous. On the south side of the cove is a most interesting ledge sloping gently at an angle of about 5° from the horizontal to the N.W., conformably with the foliation-dip of the gneiss. It is easily accessible from the cove and from the path between the cove and the lighthouse, and can be seen to extend disconnectedly to the south in Housel Bay where it is only accessible now by boat or by swimming. In the cove this ledge has a pavement composed of corrugated schistose chlorite and actinolite in which are hard lenticular and irregular masses of hornblende-gneiss, the largest being 2½ ft. in length. This exposure has a strong superficial resemblance to sheared green schist and granulite on the Wiltshire Rock (Canker Drang) and appears to mark a thrust from the north-west in the consolidated hornblende-gneiss if the present is the original slope of the sheared rock and if the movement was upward, as one would expect; but a thrust from the north-west in Cornwall one does not expect. I have not been able to find any reference to this ledge in the geological literature of the district, in spite of its accessibility in a much frequented spot. Probably it has not been examined because being conformable with the gentle foliation-dip of the hornblende-gneiss, it has been passed over as only a result of marine erosion. I hope to be able to trace it along the coast on another visit.

Proceeding from Housel Cove eastward the hornblende-gneiss can only be examined closely high up the cliffs without a boat. Epidote rocks are not conspicuous until one reaches Pen Olver. Here, and in the steep little Polledan Cove, the development of epidote bands and lenticles is extraordinary and greater than anywhere else in the Lizard. Beyond, at Bass Point, they are not so conspicuous. At Hot Point again epidote bands and lenticles are abundant in the gneiss and continue so to Church Cove, where they can also be seen in an old quarry which shows on a vertical face a wonderful flat fold, closed at either end, 6 feet long and composed of folia of hornblende, epidote and reddish felspar with accessory minerals. At Cadgwith again epidote banding is strongly developed and clearly shown in the cliffs.

Although in places the epidote rocks are such a prominent feature on the cliffs from Polbream to Church Cove, as a result of many walks and much scrambling I have come to the conclusion that gneiss with thick bands of hornblende flecked with grey or white felspar, sometimes containing porphyritic crystals of felspar or the ferromagnesian mineral, with thin bands in which felspar preponderates, is much in excess of the finely banded rock with alternations of hornblende and epidote. Sometimes the gneiss is coarse in grain, for instance at Hot Point, where a specimen was collected with crystals of hornblende reaching 3 mm. A typical specimen of finely banded hornblende and epidote-gneiss from Cadgwith contains roughly twelve bands to the inch with epidote lenticles about a quarter of an inch broad. In Polledan Cove I counted on one cliff-section thirty-seven bands of epidote and hornblende to the foot. The largest epidote lenticle I have measured (on Pen Olver) is 4 ft. by 1 ft. 4 in. The smallest are minute enlargements of very thin epidote bands.

PETROLOGY.

Before describing these epidotic rocks in greater detail I would refer for a moment to a paper by the late Prof. T. G. Bonney and Major-General C. A. McMahon (*Quart. Journ. Geol. Soc.*, xlvii, 1891) on " The Crystalline Rocks of the Lizard District ", in which, on p. 482, the authors say there should be no separation of the " micaceous and hornblendic groups ", which were the old names they employed for the Old Lizard Head Series and the hornblende-gneiss. There is a resemblance between the green schists of the Old Lizard Head Series and the hornblende-gneiss of the Landewednack area, but there are also important points of difference, given below in tabular form :—

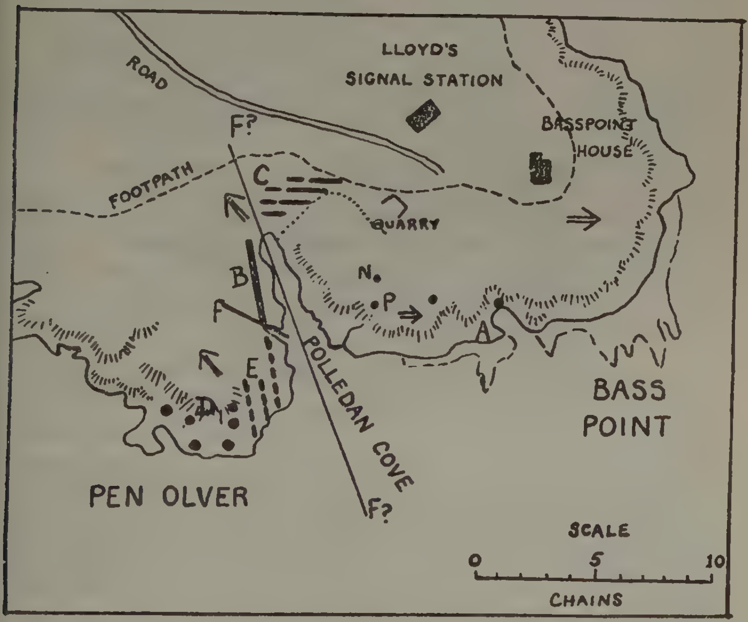
O.L.H.S. green schists.	*Hornblende-gneiss of Landewednack area.*
Generally contain quartz.	No quartz.
Hornblende acicular and in small prisms.	Hornblende in larger prisms.
Actinolite abundant, distinguished from acicular hornblende by lower refractive index and less intense colours.	No actinolite in unsheared rocks.
No pyroxene, with one possible exception (Sedgwick Mus. 21228).	Diopside abundant.
Felspar variable in quantity and composition.	Andesine a constant constituent.
Epidote, generally with quartz, forming bands and lenticles.	Epidote, generally with andesine and sometimes with garnet, apatite, sphene, and prehnite, forming more abundant and larger bands and lenticles. No quartz.

With regard to the above table, Professor C. E. Tilley says on p. 305 of his paper in this *Magazine* for July, 1937, that rocks of the hornblendic green schists and quartzose hornblende-schists of the Old Lizard Head Series have been identified as thin lava flows, sills, and tuffs. That is rather overstating the case, but those schists that contain little or no quartz may have been derived from basic igneous rocks while those that contain much quartz may have been derived from calcareous sediments. It is permissible to anticipate here a later contribution and to say that field-work has convinced me that the Old Lizard Head Series is killas like that north of the Lizard Boundary with associated basic igneous rocks very much metamorphosed ; and the absence of pyroxene in the green schists coupled with its abundance in the hornblende-gneiss is evidence that the hornblende-gneiss is not the result of the alteration of pre-existing basic igneous rocks.

With regard to the epidote, the bands and lenticles in the Old

Lizard Head Series are "epidosites" according to the definition of Reichenbach, consisting essentially of epidote and quartz (see Holmes, *Nomenclature of Petrology*, p. 92), but the name epidosite cannot be correctly applied to any of the epidote bands and lenticles in the hornblende-gneiss that I have examined. Dr. Greenly describes the epidosites of Anglesey as consisting of quartz, epidote, chlorite, and amphiboles with some albite and carbonate (loc. cit. *supra*).

Text-fig. 2 is a sketch-map of Polledan Cove and neighbourhood, where the greatest development of epidote rocks occurs, showing also the distribution of the included rocks of the Old Lizard Head Series.



TEXT-FIG. 2.—Sketch-map of Polledan Cove and neighbourhood. A, Actinolite-schist on promontory. B, Band of mica-schist and granulite 16 feet thick. C, Bands of mica-schist. Thickness of each from the top, 8 inches, 6 feet, 4 feet, 6 feet. D, Outcrops of mica-schist from Howard Fox's map. E, Outcrops of mica-schist and granulite. Shown diagrammatically. N, Mica-schist, also at dots to E.S.E. from Howard Fox's map. P, Porphyritic hornblende-gneiss, from Howard Fox's map.

Below is a brief description of slides that I have examined of the epidotic rocks, all except three having been collected by myself :—

1.	Polledan Cove.	Epidote band.	Epidote, felspar, sphene.
2.	,, ,,	,, ,,	Epidote, felspar.
3.	,, ,,	Banded rock.	Epidote, felspar, calcite, limonite, apatite, chlorite.

4.	Polledan Cove.	Epidote lenticle.	Epidote, felspar, limonite, with a band of actinolite, chlorite, felspar, apatite, and sphene.
5.	,, ,,	Epidote band.	Epidote, diopside, garnet, apatite, sphene.
6.	,, ,,	,, ,,	Epidote, diopside, felspar, apatite, sphene.
7.	,, ,,	,, ,,	Epidote, felspar, diopside, garnet, sphene.
8.	,, ,,	,, ,,	Epidote only.
9.	,, ,,	,, ,,	Epidote, felspar, actinolite, sphene.
10.	Polledan quarry.	Epidote lenticle.	Epidote, felspar, apatite, sphene.
11.	,, ,,	,, ,,	Epidote, felspar, garnet, sphene.
12.	Pen Olver.	Epidote band.	Epidote, felspar, sphene.
13.	,, ,,	,, ,,	Epidote, prehnite.
14.	,, ,,	Epidote lenticle.	Epidote, hornblende, prehnite.
15.	,, ,,	Epidote band.	Epidote, felspar, garnet.
16.	Polledan Cove.	A thinly banded specimen showing in one section for the microscope the following bands :—	

(*a*) Hornblende and epidote.
(*b*) Epidote and turbid felspar.
(*c*) Diopside and turbid felspar.
(*d*) Epidote with diopside and garnet.
(*e*) Turbid felspar and epidote with a little garnet.
(*f*) Very fine-grained felspar and diopside.
(*g*) Felspar and hornblende.
(*h*) Prehnite and zoisite (a vein).
(*i*) Epidote only.
(*j*) Epidote, garnet, and granular sphene.
(*k*) Felspar with much garnet and some epidote.
(*l*) Felspar and diopside.
(*m*) Hornblende with a little felspar.

Whenever fresh enough for optical reactions the felspar in the above rocks is found to be the plagioclase of the hornblende-gneiss.

In addition to the epidote bands and lenticles there are certain vein-rocks of later date than the epidote bands and lenticles in Polledan Cove and on Pen Olver. The following is a brief description of typical specimens, the chief features only being noted :—

Felspathic veins :

1.	Polledan quarry.	Mosaic of orthoclase and plagioclase with orthoclase phenocrysts. Sphene, epidote, and hornblende. A porphyry.
2.	,, ,,	Vein three-quarters inch thick and at least 6 yards long. Mosaic of orthoclase and plagioclase with biotite, epidote, hornblende, and abundant sphene. A porphyry.
3.	,, ,,	Plagioclase, hornblende, diopside, apatite and abundant sphene, magnetite.
4.	,, ,,	Turbid felspar, epidote, chlorite, and large crystals of sphene reaching 2·5 mm.
5.	Pen Olver.	Characteristic of many pink veins. A mosaic of felspar, chiefly plagioclase if not all, with large irregular grains of orthoclase. A little biotite and apatite. A porphyry ?

6.	At N in Text-fig. 2, south of Polledan quarry.	A vein of microgranite about one inch thick between mica-schist and hornblende-gneiss. It is slightly foliated. Quartz, orthoclase, plagioclase, biotite, and muscovite.

Quartz-veins are not uncommon, especially in and near the mica-schists, but they are not more than an inch and a half thick and are not extensive.

As we are dealing here primarily with epidotic rocks comment on the porphyry-veins and the microgranite must be postponed.

The Mica-schists and other included Rocks of Polledan Cove and Neighbourhood.

Polledan Cove and the cliffs on either side present two geological features that make them particularly interesting, the first being the abundance of epidote, the second the presence of mica-schists and other rocks intercalated with the hornblende-epidote-gneiss.

To appreciate the abundance of epidote one should descend into the cove by the route indicated by a dotted line from the quarry in Text-fig. 2. It is very steep but easy if rubber soles are worn; and a scramble over the mass of boulders that have fallen from the cliffs will be rewarded by the sight of beautiful small folds of epidote and hornblende, boulders of epidote and limonite forming green and red bands, and excellent specimens of finely banded hornblende-epidote-gneiss.

The mica-schist of Polledan Cove was described by Howard Fox in 1890 ("On the Micaceous Schists of the Penolver District", *Trans. Roy. Geol. Soc. Cornwall*, xi, part v, pp. 327–333), who included descriptions by Sir Jethro Teall of four rocks: (1) mica-schist with white mica, quartz, chlorite, garnet, and iron oxides; (2) banded hornblende-epidote; (3) epidote with a little felspar, and (4) porphyritic hornblende-schist from Pen Olver. With the paper is a map on the scale 25 in. to the mile. Howard Fox missed the fact that the general dip of the rocks on the north and west of the cove is to the N.W. and shows only local dips caused by small folds on his map. On the east the dip is to the east. He mentioned the fault that I have shown with a query: "Polledan Cove itself is occasioned by a fault." I am sure he is right because of calcite veining like that near the big fault at the south end of Pentreath Beach, but have marked it with a query because I cannot see it. Between B and E in Text-fig. 2 is another fault which Howard Fox also mentions as below an old adit level. This is visible.

Text-fig. 2 shows the distribution of the mica-schist and other included rocks. The most prominent outcrop is that at B, an iron-stained band about 16 feet thick rich in muscovite in the upper part, less so in the lower. It terminates southward at the W.N.W.–E.S.E. fault, where a section across the strike shows folds. Round E, on the steep slopes of Pen Olver, there are many exposures caused by folding and I think the 16 ft. band continues as indicated, but unfortunately there is a bit of cliff close to the fault too hazardous to venture on. Farther south the descent is easy to within 30 ft. of the sea and is worth doing to see the folding. At D are marked some exposures shown on Howard Fox's map, also at N and near A, but in many places one can see bits of mica-schist. At C are four bands of mica-schist exposed in a cliff at the north end of the cove. The eastern extremities of these bands are easily accessible but how far they continue to the west is doubtful as they cannot be examined closely. The bottom band terminates in grass. The band above that (three from the top) is of coarse, lustrous muscovite-schist, differing from the usual brownish mica-schist in the other exposures and in the cliffs on either side of Lizard Head. Howard Fox traced bands of mica-schist from C to N and beyond, but now grass hides them except for a piece here and there. The exposure at N is easily found as a flat film of mica-schist with the vein of microgranite noted earlier below it. At P is a remarkable exposure of porphyritic hornblende-gneiss in which Howard Fox said the felspar crystals are numerous and distinctly angular and regular. This rock is plainly visible now but I cannot agree with "distinctly angular and regular". It is not a hornblende-porphyrite dyke.

At A, on the promonotory to the S.W. of the little cove shown in Text-fig. 2, there is an extensive flat exposure of hornblende-gneiss with included actinolite-schist which here and there contains a few small felspar phenocrysts. The difference between the relatively coarse gneiss and the very finely acicular actinolite-schist is striking. I have found this actinolite-schist elsewhere on Bass Point and have a section showing the sharp junction between the two rocks.

The mica-schist near the Bumble Rock is finer in grain than most of the mica-schist of Polledan Cove. I had one specimen with a felspar phenocryst 8 mm. long, but it was lost in cutting a slide.

Below are descriptions of typical specimens of these included rocks that I have collected together with notes on slides I have been allowed to examine in the Survey and Sedgwick Museum collections. The descriptions are not complete: only the essential facts are mentioned.

1. Lustrous mica-schist from the north end of Polledan Cove. Muscovite and a smaller amount of biotite, folia of calcite, quartz, felspar with refractive index less than quartz where clear but mostly turbid; masses of small needles that are probably sillimanite but are too small for optical tests; garnet, apatite, magnetite.

2. Mica-schist from the upper part of the 16 ft. band. Muscovite and biotite, the latter more abundant than in 1. About equal amounts of quartz and felspar, sillimanite ? as in 1, garnet, magnetite.

3. From the lower part of the 16 ft. band. A fine-grained schistose rock consisting of biotite and felspar, all rather turbid but probably orthoclase and plagioclase. Muscovite occurs along one folium. Apatite, sphene, epidote, magnetite. No quartz.

4. From a hard band conformable with hornblende-epidote-gneiss below high-tide mark and below the 16 ft. band. This is much the same rock as 3 but has no muscovite. Some of the grains of felspar are conspicuously large but are not phenocrysts. Biotite abundant. No quartz.

5. From a hard band with hornblende-epidote-gneiss on either side. Hard amphibole-felspar-schist. The amphibole is in minute prisms of pale colour unlike the hornblende of the gneiss. The light folia are of felspar with secondary mica. Rutile, apatite, and sphene occur. No quartz.

6. From the same band as 5. Biotite-felspar schist. The felspar is in excess of the biotite. The rock might be called a granulite. Some of the felspar is clear and resembles the plagioclase of the hornblende-gneiss. No quartz.

7. From another hard band. The hand specimen resembles banded quartzite on Lizard Head and has folia of muscovite, but the slide shows no quartz. It consists of plagioclase with folia of muscovite and abundant rutile in minute crystals and grains along some of the folia. Part of this rock might be called a granulite.

8. From a hard pink band similar to 7, and also resembling the banded quartzite of Lizard Head. There are folia of muscovite and rutile is abundant, but the bulk of the rock is banded plagioclase. This, too, might be called a granulite. The felspar of this and other rocks like it appears in section as a beautiful mosaic. No quartz.

9. From another hard band, grey in colour. In section shows a felspar mosaic with subordinate chlorite and biotite and abundant rutile. No quartz. Might be called granulite.

10. (Sedgwick Museum 16880) Mica-schist collected by T. G. Bonney. This is remarkable for containing calcite distributed through the rock.

11. S.E. side of Penolver (Geol. Surv. 6830). This is a beautiful biotite-muscovite-sillimanite rock. A specimen in the Sedgwick Museum from the same locality has a little quartz. In the Memoir this is called felspathic granulite, a felspathic variety of the brown mica-schist (p. 39), but it might equally well be called mica-schist.

12. Mica-schist from cliff near the Bumble Rock. This rock occurs intercalated with hornblende-gneiss, but there is a fault in the same place which somewhat obscures the outcrop. It is finer grained than the Lizard mica-schist and most of that of Polledan Cove. It is biotite-plagioclase schist with some actinolite. Minute needles in the plagioclase are probably sillimanite. Some show positive elongation.

13. Actinolite-schist intercalated with hornblende-gneiss at Bass Point. This rock consists chiefly of needles of actinolite lying parallel to the junction with the gneiss. There are minute grains that appear to be felspar and also small " eyes " of cloudy felspar.

These included rocks then consist of mica-schist, actinolite-schist, and rocks such as Nos. 4, 6, 7, 8, 9, for which " granulite " seems to be the most suitable name, although rather indefinite, implying that though foliated or banded the rock is not easily fissile like a typical schist and that the original minerals have recrystallized as a rock which in section appears as a mosaic. What petrological name to apply to them, however, is not so important as determining if possible what they were before inclusion in the hornblende-gneiss.

I do not think there can be any doubt that these rocks are xenoliths of the Old Lizard Head Series in the hornblende-gneiss. The mica- and actinolite-schists present no difficulty, but the absence of quartzite, even of the felspathic arkoses of the Old Lizard Head Series, remains to be explained. Without a series of specimens from one to the other it is impossible to regard as proved the suggestion that the felspathic granulites of Pen Olver and Polledan Cove were originally siliceous sediments in which all the quartz has been destroyed by transfusion of material from the hornblende-gneiss magma. The absence of quartz in the Bumble mica-schist and the small proportion to felspar in any but the muscovite-rich schists of Polledan Cove may also be explained by transfusion analogous to that described by Dr. Doris L. Reynolds in Colonsay (*Mineralogical Magazine*, xxiv, 1936, pp. 307–407). The rutile of the granulites, similar to rutile in chlorite-quartz-schists at Porthallow (Geol. Survey 5225 and one of my specimens), suggests recrystallized rutile of slates and may have originated in argillaceous partings in the Polledan rocks; but without transitional specimens nothing can be regarded as proved on these lines: we do not even know whether, when the hornblende-gneiss engulfed these xenoliths, the latter were in a state of metamorphism like that of the Old Lizard Head Series to-day, or in a less altered condition.

THE ORIGIN OF THE EPIDOTIC ROCKS: A SUGGESTION.

It has been said that the origin of the epidotic rocks of the Landewednack area is one of the most difficult geological problems one could attempt to solve, and I will say at once that I have no solution to offer but only a suggestion. In the Memoir (p. 50) it is stated that "the epidote streaks and nodules are due to some kind of segregation during metamorphism. How or why this takes place is not clear . . ." The main question here, however, is why there is such an enormous amount of epidote at Pen Olver and Polledan Cove, and the fact that here also we find inclusions of the Old Lizard Head Series indicates that there may be some connection between the two phenomena.

Epidote may be (1) the result of "saussuritization" of felspar, (2) an alteration product of ferromagnesian minerals, (3) a result of contact metamorphism, (4) an original mineral in an igneous rock. The first two require no comment. As an example of contact metamorphism may be mentioned very siliceous conglomerate impregnated with epidote at a granite junction in Malaya; and in Malaya also are good examples of epidote as an original rock-constituent, such as an epidote-granophyre, an epidote-diopside-granite, and epidote sometimes accompanied by allanite in rocks associated with hornblende-granite.

In the Old Lizard Head Series there is much hornblende-schist and actinolite-schist. There may therefore be inclusions of hornblende-schist belonging to that series in the hornblende-gneiss as well as of actinolite-schist, and there is the possibility that some of the hornblendic rocks interbanded with epidote are hornblende-schists of the Old Lizard Head Series. The four-inch band near the Bumble Rock may belong to this Series too. There is a further possibility. Among the Old Lizard Head Series rocks containing hornblende and actinolite are some which are best explained as altered calcareous sediments, which accords with J. B. Hill's description of the killas he mapped as "Veryan" immediately to the north of the Lizard Boundary. On p. 166 of the Memoir is the following: "Although the killas of the Veryan Series is frequently calcareous, limestones are of rare occurrence. Small bands, a few feet in thickness, are seen at Nelly's Cove, Porthallow, and on the coast to the north of this, and narrower seams an inch or more in width may be observed in the killas between Polurrian and Gunwalloe; bands of limestone also occur in association with the pillow lavas and radiolarian cherts of Mullion Island."

The limestones near Porthallow are well known and are described by Dr. E. M. L. Hendriks as lenticles in calcareous shales and mudstones (plate xxiii of her paper in *Quart. Journ. Geol. Soc.*, xciii, 1937). My contention that the Old Lizard Head Series is killas like that north of the Lizard Boundary, but much more metamorphosed, is not original. A. Somervail appears to have held that view, expressed very cautiously (*Trans. Roy. Geol. Soc. Cornwall*, xi, part ix, 1894, pp. 662–8); and from private communications I know that Somervail was not the only deceased geologist of that opinion.

The age of this killas need not detain us here: the important point is the existence of calcareous killas and limestone. If they occur north of the boundary I see no reason why they should not occur south of it or why the limestone beds should not be thicker. Now consider the mineral association of the epidote bands and lenticles of Pen Olver and Polledan Cove. Epidote is the chief mineral, with about 24 per cent of lime; with it are soda-lime felspar, calcite, diopside, garnet (which has not been analysed and could only be separated with difficulty but has the appearance of grossularite and is distinct from the garnet of the mica-schists which is believed to be almandine), prehnite, actinolite, apatite, and sphene. In one of the mica-schists calcite-folia are seen, while in another calcite is distributed throughout the rock. Clearly a lot of lime was available and a source for that lime is required. I suggest it was calcareous killas and limestone caught up and absorbed by the hornblende-gneiss magma. Obvious objections to this suggestion are that no limestone is known in the Old Lizard Head Series and that no inclusions of that series are known except at Pen Olver, Polledan Cove, Bass Point, and near the Bumble Rock, though epidote is very abundant, but not so abundant, at Hot Point and Cadgwith. Wherever it is abundant, however, calcareous rocks may have been absorbed completely.

With regard to the epidosites of the Old Lizard Head Series, the epidote can only be regarded as a product of metamorphism; and there may be some such epidosites included in the hornblende-gneiss and "felspathized" by transfusion. Where epidote bands and lenticles in the hornblende-gneiss are few, as at Mullion, they may be a segregation of an original rock-constituent but they may also be the result of contamination.

Therefore at Pen Olver and Polledan Cove there may have been three sources of the epidote in the bands and lenticles: (1) epidote that was an original rock-constituent of the hornblende-gneiss, (2) epidote derived from the Old Lizard Head Series, and (3) epidote formed as a result of contamination by calcareous rocks. About the present distribution of the epidote I can say no more than is contained in the quotation above from p. 50 of the Memoir. There must have been segregation of epidote, just as there has been segregation of hornblende, but exactly how it was brought about we do not know. The chief fact we are dealing with here is the enormous amount of epidote in a certain locality among the cliffs of hornblende-gneiss, where also there are xenoliths of the Old Lizard Head Series, and I believe that the great amount of epidote present is due to contamination by other xenoliths of calcareous rocks that have been completely absorbed, but I cannot prove it.

I should have said in my first "note" that the datolite of Parc Bean was found by Sir John Flett and described by Dr. W. F. P. McLintock.

REVIEWS.

AN INTRODUCTION TO GEOLOGY. By A. E. TRUEMAN. pp. ix + 258 with 133 line drawings. Murby. 4*s.*

TO give an intelligible account of the whole of geology from elementary mineralogy to the theory of continental drift within the compass of a small school book is a formidable task: nevertheless it has been accomplished with success by Professor Trueman. In the preface it is stated that the book "has been prepared primarily for use in schools" and the distribution has clearly been planned to that end. The greater part of the space has been set aside for those parts of the subject readily available for field study in most places in these islands, such as the agents of weathering and transport, geological structure, and the sedimentary rocks, while igneous and metamorphic rocks are treated shortly and only one chapter is allowed for stratigraphy. One chapter each is devoted to minerals and fossils, these are well planned and with the help of the illustrations should prove a useful guide to a simple series of specimens. At the end of each chapter a note is appended with suggestions for practical or experimental work. The style of the book is clear and the writing has been done with a remarkable economy of words, the illustrations are well chosen and numerous though a few others might have been added with advantage. The book seems well suited to the purpose for which it was written and should appeal also to those who wish to obtain some acquaintance with geology but who have not time or inclination to read the larger textbooks.

W. H. W.

CARTA GEOLOGICA DELLE ALPI NORD-OCCIDENTALI, 1 : 200,000. By F. HERMANN. Basel: B. Wepf and Co. Price 35 Swiss francs.

THIS map in two sheets, with explanatory notes in Italian and French, is also accompanied by a structural map on the scale of 1 : 750,000. It has been constructed on the basis of all work published up to 1937, supplemented by some unpublished matter as well as by the author's own field work extending over thirty years. The work is limited to the North-Western Alps, north of the 45th parallel: it comprises the Italian slope and wide regions of the French and Swiss side, so as to show all that is included between the jaws of Termier's vice, the jaws themselves, and part of the nappes thrust over them.

WISSENSCHAFTLICHE ERGEBNISSE DER NIEDERLÄNDISCHEN EXPEDITIONEN IN DEN KARAKORUM, ETC. By P. C. VISSER and J. VISSER-HOOFT. Band II. pp. viii + 216, with maps and 98 text-figs. Leiden: Brill, 1938.

IN this volume an account is given of studies of the glaciology of the Karakorum and other ranges during four expeditions in the years from 1922 to 1935. These show glacial phenomena on a scale only equalled in polar regions, and are therefore specially instructive as regards the great glaciations of the past. During these expeditions a great number of hitherto unknown glaciers, many of the largest size, were discovered, and it is calculated that as much as 28 per cent of the whole Karakorum chain is occupied by glaciers, or about 5,000 square miles, and in spite of the latitude some glaciers come down as low as 7,000 feet. The longest glacier, the Slachen, is almost exactly three times the length of the Aletsch, with just ten times the area.

It is impossible to summarize here the innumerable points of interest discussed in this admirable work. It should be read carefully by all geologists interested in glaciation, while explorers and climbers will find much of value. Many of the illustrations are very fine.

CONTRIBUIÇÃO PARA O ESTUDO DOS GRANITOS DA SERRA DA CANTAREIRA. By L. F. DE MORAES REGO and T. D. DE SOUZA SANTOS. pp. 162 with 50 figures and a case of maps. São Paulo, 1938.

THIS publication, which fortunately includes summaries in English, French, and German, gives a full petrographical description of certain granites in the immediate neighbourhood of São Paulo in Brazil, together with an investigation of their physical properties as building stones and material for concrete. The granites form a great batholith, believed to be of Algonkian age, and certainly pre-Devonian. Several types of granite are present, differentiated from an original magma at the time of intrusion, with accompanying aplites, pegmatites, and basic dykes. They were intruded into and metamorphosed the San Roque Series, now schists, quartzites, and paragneisses. The next directly overlying formation is Tertiary, but fossiliferous and unmetamorphosed Devonian and Silurian rocks have been found not far away.

R. H. R.

ANNOUNCEMENT.

INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS.

INFORMATION has been received that the President of the United States has invited the International Union of Geodesy and Geophysics to hold its seventh general assembly in the United States in 1939. The invitations have been extended on behalf of the President by the Department of State through its diplomatic missions to the governments to which these missions are accredited, and invite the participating countries to be represented by delegates on this occasion.

It is planned to hold this seventh triennial assembly of the Union in Washington, 4th–15th September, 1939, according to a statement made by Dr. John A. Fleming, Director of the Carnegie Institution's Department of Terrestrial Magnetism, who is General Secretary of the American Geophysical Union. The American Geophysical Union is the American Section of the International Union of Geodesy and Geophysics, and its Executive Committee is the Committee on Geophysics of the National Research Council. The Council is collaborating with the American Geophysical Union as host to the assembly. The last general assembly of the International Union was held at Edinburgh in September, 1936.

CORRESPONDENCE.

PETROGRAPHIC NOMENCLATURE.

SIR,—As Chairman of the British Association Committee on Petrographic Nomenclature I welcome the article by Dr. A. K. Wells in your September issue, and I hope it will provoke discussion of the tentative proposals put forward in 1936 for a grain-size classification. No comments were ever received on those proposals from British petrologists and, lacking encouragement, the Committee has not proceeded with the scheme. I am glad to take an opportunity of reminding your readers that this Committee on Nomenclature is still in being and earnestly invites (*a*) comments on the tentative proposals for a grain-size classification (GEOL. MAG., 1936, LXXIII, p. 319) and (*b*) suggestions for points of nomenclature for discussion by the Committee. All communications should be addressed to me at the British Museum (Natural History), South Kensington, London, S.W. 7.

W. CAMPBELL SMITH.

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ORIGINAL ARTICLES.

Some Petrological Studies in the Harlech Grit Series of Merionethshire. III. The development of Pyrite in the Grits and Mudstones.

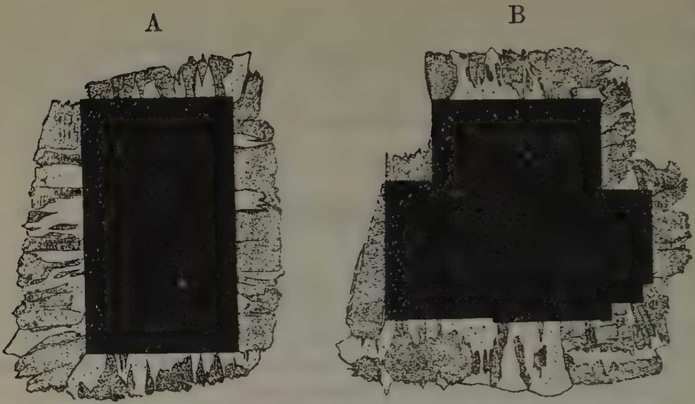
By Austin William Woodland, Department of Geology, Queen's University, Belfast.

I. Introduction.

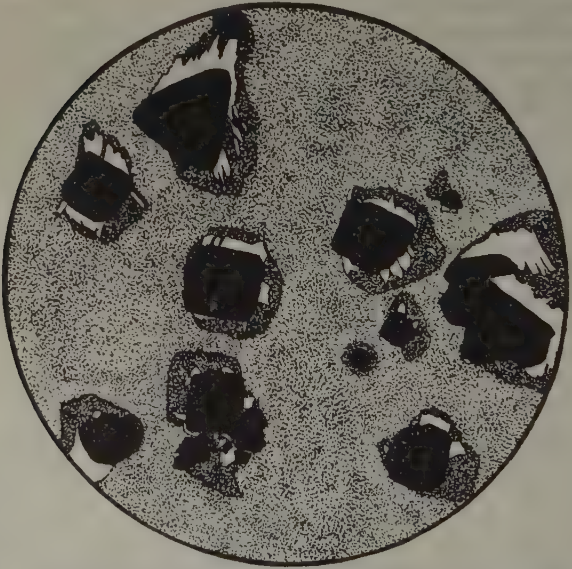
IN the Harlech Grit Series pyrite always occurs associated with rocks of practically all grades. It is, on the whole, of least importance in the grits, but even in these it becomes locally fairly abundant. Among the mudstones it occurs concentrated into layers, which are relatively persistent laterally. Immediately below the manganese-ore of the Manganese Shale Group, for example, there occurs a very widespread band of green mudstone which contains abundant pyrite crystals. Although its general characters are the same this band varies slightly in detail when traced laterally and it is with these variations that the present paper is largely concerned. This band is usually 1 to 2 inches thick and is usually of dark green mudstone, though rarely it is of the normal blue-grey colour. The pyrite crystals vary from very minute to about $\frac{3}{8}$ inch in size. In addition, pyrite occurrences from other rocks are described. The account is particularly concerned, not with the pyrite crystals themselves, but with zones of authigenous minerals which almost invariably surround them in these rocks.

II. Petrographic Characters.

The simplest type is that in which the crystals are surrounded by a zone of fibrously intergrown chlorite and chalcedonic silica. These occur in all types of rocks. Particularly well developed crystals with such zones were obtained from a grit about 40 feet above the base of the Manganese Group at the Cwm-yr-Afon Mines (Artro Valley, Llanbedr District), and are seen in Text-fig. 1. The pyrite crystals occur in well developed cube forms, often with unequal development of the axes. Usually simple crystals are developed (Text-fig. 1 A), but sometimes crystals consisting of a cluster of

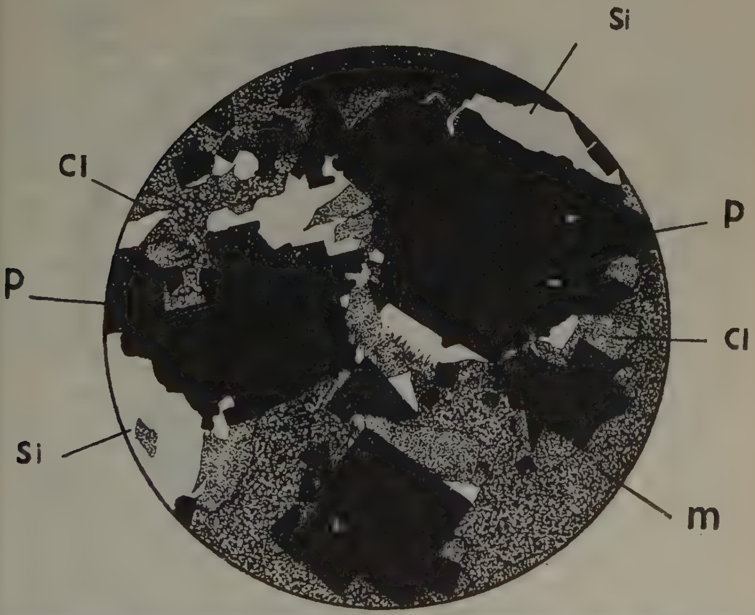


Text-fig. 1.—Pyrite crystals from a grit about 40 feet above the base of the Manganese Shales, Cwm-yr-Afon Mines. The pyrite crystals are surrounded on all sides by a fibrous intergrowth of bright green chlorite and chalcedonic silica, the interlocking fibres being developed with their long axes parallel to the crystal faces. A. Simple crystal of pyrite. B. Compound crystal.



Text-fig. 2.—Pyritiferous rock below the Manganese ore; Cell-fechan, near Barmouth. Pyrite crystals with surrounding chlorite-silica zones embedded in a fine-grained matrix. Magnification, 13 diams.

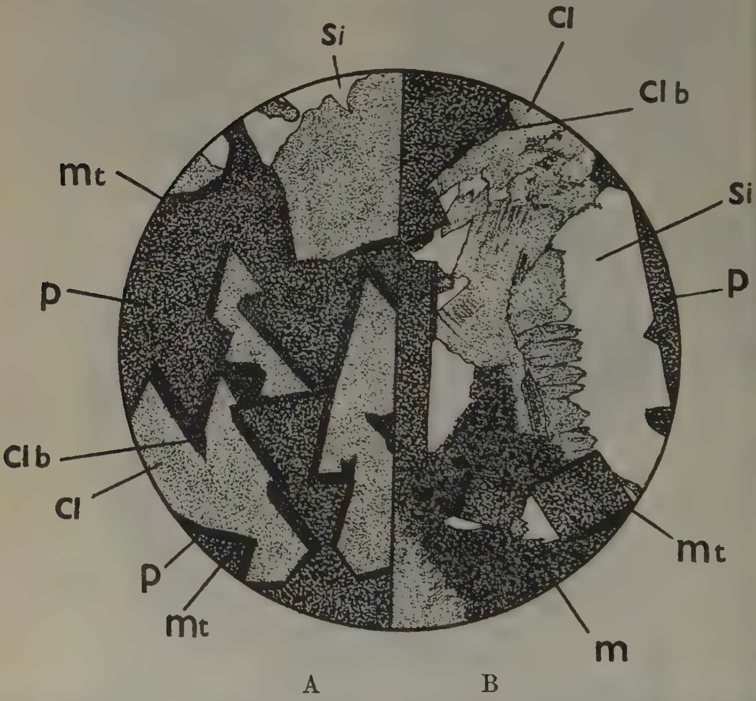
interfering individuals growing along approximately parallel axes, occur (Text-fig. 1 B). The chlorite and the silica fibres interlock perfectly and they are orientated with their length at right angles to the crystal faces they adjoin. The silica is clear and colourless and its fibrous character is best seen between crossed nicols. The chlorite is green and has a well-marked pleochroism from yellowish-green to emerald green, the greatest absorption being at right angles to the length of the fibre. The interference colours are ultra-blues and purples.



Text-fig. 3.—Pyritiferous layer below the manganese-ore; east side of Llyn Dywarchen. The pyrite occurs in isolated and compound crystals with surrounding zones of chlorite and chalcedonic silica. Note the tendency for the individuals of the same compound crystal to have the same crystallographic orientation. P, pyrite; Cl, chlorite; Si, silica; m, rock matrix. Magnification, 13 diams.

Not always are the crystals and their surrounding zones so perfectly developed. Text-fig. 2 shows a typical example of the pyritiferous layer below the manganese ore at Cell-fechan, $\frac{1}{4}$ mile north-east of Barmouth. The pyrite crystals, about 1 mm. in size, occur in individual layers parallel to the bedding, throughout a green or grey-green striped mudstone of uniformly fine grain. The amount of pyrite developed in any layer varies considerably from occasional crystals, through closely packed crystals in layers one crystal thick, to layers up to $\frac{1}{4}$ inch thick, and the concentration varies laterally. For the most part the crystals consist of irregular cubes, sometimes with curved faces and rounded coigns, and in a less degree of irregular masses, and each is surrounded by a zone of chlorite and chalcedony. Frequently some faces have no zonal development, but no crystal was observed in which it was entirely absent.

In some of these rocks the pyrite is present in great abundance and compound crystals have developed, largely to the exclusion of simple isolated crystals. These usually show, on their margins, good euhedral boundaries with typical rectangular and triangular outlines. Within individual clusters the crystals are usually orientated



Text-fig. 4.—Pyritiferous band below the manganese-ore ; east side of Llyn Dywarchen. A. Shows the magnetite zone surrounding the pyrite crystals associated with green chlorite. Note also the occurrence of the brown chlorite between the magnetite and the green chlorite, and the parallel orientation of the individuals of a cluster of crystals. B. The magnetite zone is absent when silica is present in the surrounding zone. The matrix contains abundant small authigenous crystals of magnetite. Mt, magnetite; p, pyrite ; Cl, green chlorite ; Cl.b, brown chlorite ; Si, silica ; M, magnetite bearing matrix. The opaque minerals are represented in reflected light and the transparent minerals in ordinary light. Magnification, 40 diams.

haphazardly, but sometimes they appear to possess the same orientation. Text-fig. 3 shows an example of a cluster of similarly orientated crystals, cut normal to one of the axes, while in Text-fig. 4 A such a cluster is cut oblique to the axes. Abnormal development along one or two of the axes is not uncommon, very elongate rectangular crystals resulting. The development of the surrounding zones is frequently irregular when the pyrite is very abundant, owing to the mutual interference of crystals, and the arrangement and nature of these zones is subject to local modification, some sides of the crystals or crystal clusters possessing wide zones, while on others they may be entirely absent.

In general these zones vary from about one-fifth to one-quarter of the depth of the crystal, i.e. the total area in section of the zonal materials tends to equal about one-half that of the crystal around which they are developed. Sometimes chlorite may be developed to the virtual exclusion of silica (Text-fig 4), but never, however, is silica observed to occur alone, though it sometimes makes up as much as two-thirds of the zone. When both are developed normally, the silica tends to take up the interior portion of the zone, adjoining the crystal, and the chlorite is more or less confined to the outer portions. The zones are remarkably free from inclusions of the matrix, and the junctions of the zones with this are well defined.

Interesting modifications of this standard type occur. The most usual one is one in which the crystals show, on some of the margins, at least, a regular zonal development of magnetite, which stands out very clearly from the pyrite in reflected light. This was particularly well developed in the pyrite-bearing band below the manganese ore at Llyn Dywarchen (north of Cwm Bychan, Llanbedr region), as shown in Text-fig. 4. The thickness of the magnetite zone varies slightly along different faces of the same crystal, but along any one face the zone is remarkably uniform in behaviour, being of constant thickness and adhering tightly to the face of the crystal. In thickness these magnetite zones vary from 0·012 mm. to 0·060 mm. They are almost invariably present in these rocks when chlorite is developed to the exclusion of chalcedony (Text-fig. 5 A). When the silica is present, however, it occupies, as usual, the internal part of the chlorite-silica zone, and in the case there is a marked tendency for the magnetite zone to be absent from the face of the crystal (Text-fig. 4 B).

When this magnetite occurs, surrounded on the external side by green chlorite, it is not unusual to find a small irregularly developed zone of yellowish-brown chlorite between the magnetite and the green chlorite. This chlorite has a higher refractive index and a greater birefringence than the green variety, and it appears to be a form rich in ferric oxide. This brown chlorite is never observed in any other position but adjacent to and external to the magnetite zone.

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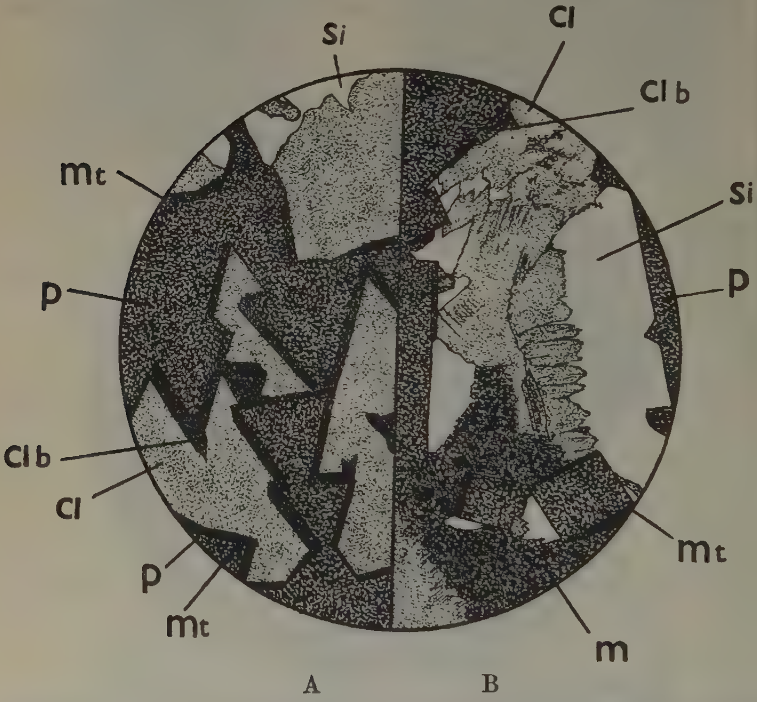

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coincident with the bedding of the rocks. The best example of this is the pyrite-bearing mudstone immediately below the manganese-ore, which is present at exactly the same horizon throughout the whole area.

The relative age of crystallization of the pyrite crystals is deduced from a consideration of the zones of secondary material surrounding them. A. Harker (1889, pp. 396–7) described zones of secondary chlorite and silica surrounding pyrite in slates. He deduces that "the pyrite is of very early origin, and that it became coated at an early stage with a chloritic envelope; further that the rock became thoroughly compacted before it was subjected to the lateral thrust, so that in yielding it was able to leave vacant spaces, which were filled at a later date by crystalline quartz". According to his view the silica zone post-dates the pyrite and is contemporaneous with the cleavage, while the pyrite and chlorite are pre-cleavage. However, many of the rocks in the present instance show no cleavage structures and yet the pyrite occurs surrounded by chlorite-silica zones, having no elongate arrangement in "eyes".

The zones are regarded as being formed by the infilling of spaces around the pyrite by secondary materials from circulating solutions. These spaces were the direct result of the contraction in volume consequent upon the crystallization of the pyrite. Such spaces could only be formed after the rock matrix had attained a rigid state, otherwise loose and unconsolidated material would have adapted itself to the decreasing volume and infilled any spaces that would be formed. The junctions of the secondary zones with the rock matrix are abrupt and indicate that the latter did not adapt itself to the decrease in volume caused by the formation of the pyrite crystals. The crystallization of the pyrite, therefore, took place at some time after the consolidation and induration of the rock. Some samples are noted in which pyrite crystals are disrupted by cleavage, and so its formation pre-dates it. The actual crystallization is regarded as having been induced by the downward pressure exerted by great thicknesses of superposed materials.

The indications are that the sulphide was originally deposited in a finely disseminated state throughout the sediment and that when crystallization was initiated this diffused towards points of actual crystallization now represented by the pyrite crystals themselves. Thus the first stages of these metamorphic changes is represented by the localization of the iron sulphide itself, before its crystallization, into clots to the exclusion of rock matrix, in a similar manner to the formation of concretionary structures, which in some rocks are presumed to be the result of processes of diffusion and crystallization. The transformation of ordinary iron sulphide to crystalline pyrite involves a considerable contraction in volume, which would then result in the formation of spaces, now infilled by secondary material, around the crystals. Ordinary black amorphous iron sulphide (approximating to FeS) is precipitated from solution in natural waters and it has often been recorded occurring in a finely divided state in, for example, Coal Measure shales and Rhaetic Black Shales. The crystallization of the pyrite (FeS_2) from such material would apparently involve the liberation of iron (according to $2FeS = FeS_2 + Fe$); this, if liberated, could form, under these pressures, magnetite by combination with, say, water in what would be a zone of dehydration. The almost invariable presence of large quantites of authigenous magnetite in the pyrite-bearing rocks, and the occurrence of minute euhedra enclosed within the larger pyrite crystals indicates contemporaneous crystallization of magnetite and pyrite, and seems to bear out a reaction of this nature:

$$6FeS + 2O_2 = 3FeS_2 + Fe_3O_4.$$

It does appear to be a fact, as far as these rocks are concerned, that pyrite never crystallized without the separation also of magnetite. The Fe available for the formation of magnetite diffused evenly into the rock matrix, so that in calculating the percentage decrease in volume on formation of pyrite from ferrous sulphide only the volumes of FeS before, and of FeS_2 after the reaction need be considered. The ratio required, therefore, is "volume of 2FeS": "volume of FeS_2," which works out to be approximately 3 : 2. That is, the surrounding zone would be approximately half the volume of the pyrite crystal, which is in accordance with the observed facts (p. 533).

With regard to the zonal developments, the materials forming them obviously depend upon the nature of the circulating solutions from which they are derived. The properties of the zone may be summarized as follows:—

(1) Frequently they are composed only of chalcedony and chlorite, the proportions of the two varying considerably.

(2) Although chlorite may occur to the virtual exclusion of silica, the latter hardly ever occurs without chlorite.

(3) When both occur they are fibrously intergrown, with the silica occupying the internal portions of the zone adjacent to the pyrite.

(4) When silica is absent, a regular zone of magnetite often intervenes between the chlorite zone and the pyrite face. This tends to be absent when silica is developed.

(5) Between the magnetite and the chlorite zones is developed an irregular zone of yellowish-brown chlorite.

(6) Occasionally a zone of siderite is developed. When silica is absent it occurs on the internal side of the chlorite and is usually separated from the pyrite by a narrow zone of magnetite. If silica is present it takes up a position between it and the chlorite.

(7) All the constituents (except magnetite) have a fibrous habit and the fibres are orientated at right angles to the crystal faces.

Now, the formation of the surrounding face would synchronize with the crystallization of the pyrite and that face would be filled up progressively as it was formed. The part of the existing space to be first filled would be that furthest away from the centre of crystallization, and the last part, that nearest the centre, since contraction took place towards that centre. That is, the portions of the zone immediately surrounding the crystal were the last formed. Since crystallization of the secondary materials took place progressively with the formation of the space, the order of crystallization of these constituents is represented by the sequence from the external parts of the zone to the pyrite, that now adjoining the pyrite being the last to crystallize. From the minerals present it is deduced that the materials in the circulating solutions were: alumina, iron compounds, silica, and rarely carbonic acid. Upon the relative amounts of these constituents depended the final composition of the zone surrounding the pyrite.

Silica crystallized out after chlorite and consequently it represents excess of silica over the metallic oxides with reference to the amounts necessary to form green chlorite. When the magnetite zone is present, it was the last to crystallize, and since no silica is associated with it, it represents an excess of iron over silica with reference to the amounts required to form green chlorite. The brown chlorite, crystallizing after the green but before the magnetite, appears to indicate an increasing enrichment in iron of the circulating solutions, an enrichment finally resulting in the separation of magnetite. A significant fact is that the magnetite zone has only been observed in those rocks, in which the rock matrix has developed large quantites of authigenous magnetite, i.e. where a rock very rich in iron could give circulating solutions rich in iron.

Since the siderite zone is developed around crystals when silica is both present and absent, its formation clearly does not depend upon iron-rich or silica-rich solutions. It clearly separates immediately after the green chlorite, whether or not silica crystallizes, and its separation appears to depend solely upon the presence of carbonic acid.

Thus the sequence of mineral crystallization in the zones surrounding the pyrite may be summarized as follows:—

A. Carbonic acid absent.
  1. Solutions SiO_2-rich : green chlorite → silica.
  2. Solutions iron-rich : green chlorite → brown chlorite → magnetite.

B. Carbonic acid present:
  1. Solutions SiO_2-rich : green chlorite → siderite → silica.
  2. Solutions iron-rich : green chlorite → siderite → magnetite.

With regard to the precipitation of the iron sulphide itself, it seems impossible to appeal to the normal method by reduction of iron sulphate by decaying organic matter. The associated rocks show no traces of organic or carbonaceous matter, and the total absence of fossils in rocks entirely suitable for their preservation indicates that life was impossible in these waters. This would probably be due to the abnormally high percentages of manganese in solution as suggested by the precipitation of the carbonate from these waters to form a rock containing many times more manganese than iron, whereas the normal ratio of iron : manganese is about 40/70 : 1 (Beyschlag, Vogt, and Krusch, 1914, p. 979). It appears, therefore, that the sulphide must have been formed by the direct action of soluble sulphides on soluble iron salts. Van Hise (1904, p. 1107) states that sodium carbonate, one of the most abundant salts in ground water, is capable of dissolving natural sulphides to form sodium sulphide, which is carried on in solution. The large concentrations of carbonic acid in solution in these waters (as evidenced by the great dialogite deposits) would in all probability be associated with a fair amount of soluble sulphide. He also states that "carbonates of alkalies are among the most abundant compounds carried by underground solutions, and hydrogen sulphide is known to be very common in such solutions".

The work entailed in this and the two previous papers of the series was carried out in the Department of Geology, University College of Wales, Aberystwyth, and the author wishes to express his thanks to Professor H. P. Lewis, under whose direction the work was performed.

IV. LIST OF WORKS TO WHICH REFERENCE HAS BEEN MADE.

BEYSCHLAG, VOGT, and KRUSCH. 1914. "Ore Deposits."
HARKER, A. 1889. "On 'eyes' of Pyrite and other Minerals in Slate": GEOL. MAG., XXVI, 396–7.
VAN HISE, C. R. 1904. "A Treatise on Metamorphism": *Monog.* 47, *U.S. Geol. Surv.*

The Proximal End of *Cryptograptus*.

By O. M. B. BULMAN, Sedgwick Museum, Cambridge.

IT has long been suspected that the mode of development of the proximal end in *Cryptograptus* may differ considerably from the ordinary Diplograptid type, but the preservation of the material has hitherto been too poor to allow of a complete interpretation. Amongst the graptolites preserved in impure limestone nodules[1] in the Balclatchie Shales at Laggan Burn, near Girvan, *Cryptograptus tricornis* is abundant, and despite the extreme tenuity of the periderm, specimens can be dissolved out with HCl and HF, in a remarkably good state of preservation. Several such specimens have been sectioned and a model made of the proximal end, and the remainder of the material mounted either dry (for external features) or in Canada balsam, in which the thin periderm is to a large extent transparent and the course of the growth lines can be followed. It is hoped to publish in detail figures and descriptions of this material, including sections and model, in an account of the complete graptolite fauna of this horizon; but such an account will take several years to complete and it may be of use to other workers on the graptolites to publish in the meantime a preliminary note on the structure of the proximal end in the genotype of *Cryptograptus*.

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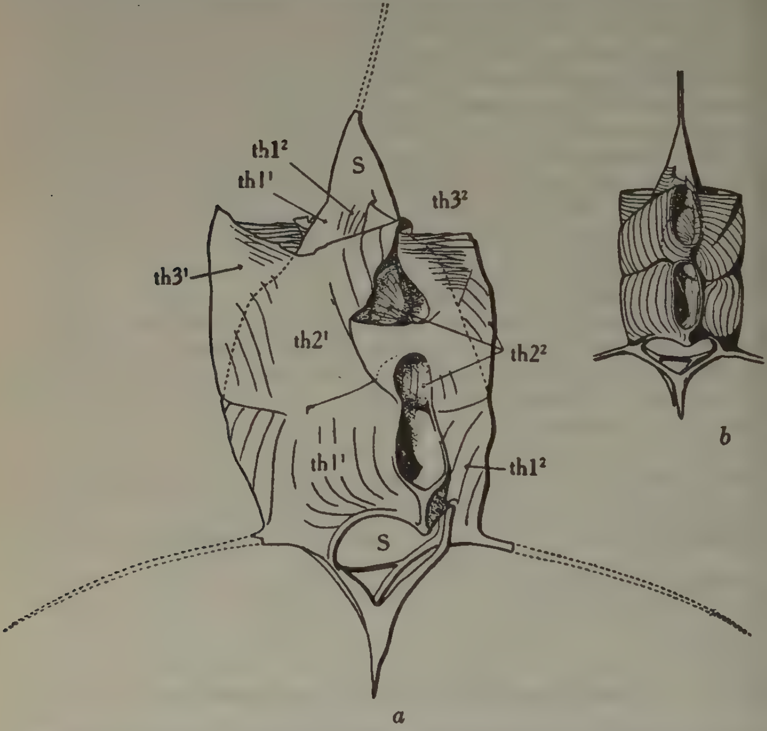
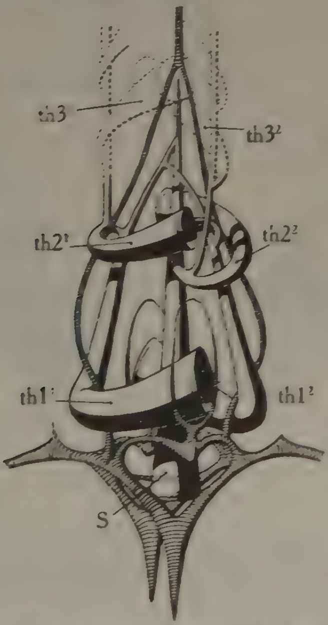
[1] I am most grateful to Dr. John Pringle, who has collected and given to me a large quantity of this limestone. At his request, I shall present all figured material to the Geological Survey Museum; the specimens shown in Text-figs. 1 and 3 bear my temporary numbers.



Text-fig. 1 *a*.—Proximal end of *Cryptograptus tricornis* (Carruthers) reverse view. Specimen 119 b. × 30 approximately.
Text-fig. 1 *b*.—Restoration of the same, somewhat diagrammatic.

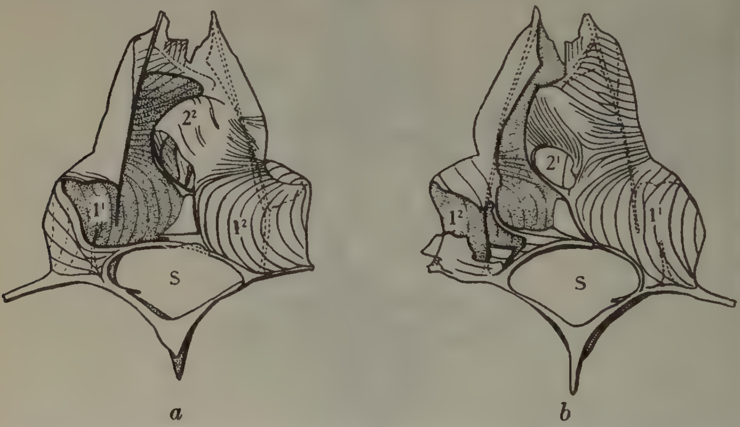
The sicula is represented by two thin diverging chitinous rods connecting the nema (virgula) to the base of the rhabdosome; in well-preserved specimens, a very thin, apparently structureless, chitinous membrane is stretched over these rods at the apex, forming the prosicula and part of the metasicular portion. The bulk of the metasicular wall seems to be entirely unchitinized, and the cavities of th1^1, th1^2 and the distal part of the metasicula are merged into a single space (Text-fig. 3 *a* and *b*).

Theca 1^1 seems to originate, left-handedly, very high up on the sicula, and th1^2 to bud from th1^1 at a very early stage. There is some doubt regarding the actual origin of these: but in one of the section series, a slight ridge on the inside of the sicular cavity affords evidence of the point of origin of th1^1, and the connecting canal of th1^2 is indicated by rather obscure growth-lines in several specimens (e.g. Text-figs. 1 and 3). Both of these thecae grow downwards beside the sicula to the level of the sicular aperture: they then turn at right angles and each grows horizontally round (outside) the base of one of the longitudinal rods which constitute the more apertural part of the sicula. Each then grows very slightly upwards, to open a little above the level of the aperture of the sicula, on the side opposite that on which it originated.



Text-fig. 2.—*Cryptograptus tricornis* (Carruthers); thecal diagram, combined with a diagram of the principal lists of the proximal end (shaded). Growth beyond the stage represented by the specimen in Text-fig. 1 is shown by dotted lines.

The most distinctive feature of the development, however, concerns the mode of origin of th2^1 and th2^2; these arise from th1^1 and th1^2 respectively, and the type of development is entirely unlike any previously described Diplograptid, though it may be regarded as a modified Dichograptid type. Both these thecae appear to have developed at an early stage of growth, while th1^1 and th1^2 were less than half-grown. Their direction of growth is difficult to describe but may be visualized from the thecal diagram (Text-fig. 2) and Text-figs. 1 and 3. In th2^2 there is at first a distinct upward growth, the theca subsequently turning down, outwards and round, above th1^2; th2^1 has apparently a more horizontal initial growth, subsequently turning down, out, and round above th2^1. In the proximal part at least, the two stipes composing the biserial rhabdosome have a very unusual orientation, lying side-by-side instead of the normal back-to-back arrangement, and this was recognized by Hadding.[1] The two rows of thecal apertures are situated along the obverse and reverse sides, not along the lateral sides of the rhabdosome as in ordinary Diplograptids



Text-fig. 3.—Immature proximal end of *Cryprograptus tricornis* (Carruthers), *a*, reverse, and *b*, obverse aspect, specimen 170 a. × 25 approximately.

This structure of the proximal end fully justifies the removal of *Cryptograptus* from the family Diplograptidae Lapworth, and indeed their origin and descent must have been entirely distinct. Hadding (1915, loc. cit.) proposed the family Cryptograptidae, to include *Cryptograptus*, *Glossograptus*, *Lonchograptus*, and *Nanograptus*, but it does not seem to have been well received; we must now accept the need for such a family to contain *Cryptograptus*, but the position regarding the other three genera he included is still a little uncertain. It is perhaps convenient, provisionally at least, to leave *Glossograptus* Emmons (and *Lonchograptus* Tullberg, which is generally considered a synonym) in the family Glossograptidae Lapworth, for its mode of development is not properly understood and there are conflicting views as to the structure of the stipe. Regarding *Nanograptus*, however, the growth stages of *N. lapworthi* Hadding seem to agree in essentials with the structure of *Cryptograptus* described above, making allowance for greater chitinization of the sicula in *Nanograptus*, and this genus is probably nearly allied.

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[1] Hadding, A., 1915, "Om *Glossograptus*, *Cryptograptus* och tvenne dem närstående Graptolitsläkten," *Geol. Fören. Förh.*, Bd. xxxvii, p. 304.

At least four main lines of descent in the biserial graptolites have already been tentatively indicated,[1] but in all those except *Oncograptus*, the proximal end had attained the Isograptid or higher stage of development before the rhabdosome acquired its biserial character. *Cryptograptus* resembles *Oncograptus* in this respect, that it must be descended from some Dichograptid at a primitive stage of development—the *bifidus* stage of the Dichograptid type—and the possibility of some relation between *Oncograptus* and *Cryptograptus* cannot now be excluded.

Problems of Ammonite Nomenclature.

3. ON *AMMONITES VARIANS* J. SOWERBY.

By L. F. SPATH.

AMMONITES VARIANS J. Sowerby[2] is a composite species, based on five syntypes, which are preserved in the British Museum (Natural History),[3] and have long been accessible to any reviser who wished to select a lectotype from among these syntypes. Nobody, however, has yet done so. In the days of the early revisers, of course, from Mantell and Brongniart (1822) to Sharpe (1853), nomenclatorial restrictions were unknown ; and even when Semenow (1899)[4] dealt with Sowerby's species, he accepted the customary interpretation of *Schloenbachia varians* without going back to Sowerby's original description and figures. Semenow took d'Orbigny's[5] excellent figure as typical, and his restriction seemed to me convenient to adopt,[6] if not actually binding. But on going more fully into the matter I discovered not only that Semenow's selection (if it be selection) is not valid but also that none of the forms which authors nowadays identify with *Schloenbachia varians* agrees either with Sowerby's description or with any of the syntypes in the British Museum. It is thus highly desirable to discuss this common zonal ammonite species and place its interpretation on a sound footing.

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[1] Bulman, O. M. B., 1938, *Handbuch der Paläozoologie*, Borntraeger, Berlin, Bd. 2D, Lief. 2, p. 58, table ii.

[2] *Mineral Conchology*, ii, 1817, 169, pl. clxxvi, figs. 1–6.

[3] See Crick, *List of Types of Fossil Cephalopoda*, London, 1898, p. 28.

[4] "Faune des dépôts crétacés de Mangychlak, etc.", *Trav. Soc. Imp. Nat. St. Pétersb.*, xxviii, livr. 5, 1899, p. 102.

[5] *Pal. Française, Terr. Crétacé*, i, 1841, 311, pl. xcii, figs. 3–4.

[6] "New Ammonites from the English Chalk," GEOL. MAG., LXIII, 1926, 81. "On the Zones of the Cenomanian and the Uppermost Albian," *Proc. Geol. Assoc.*, xxxvii, 1926, 426, 430.

Mantell[1] was the first to restrict Sowerby's species; and since he definitely included the originals of figs. 1, 2, 3, 4, and 6 (four specimens) in his var. *tuberculata*, the fifth specimen, namely the original of fig. 5 (= left-hand lowest figure) would appear to have been chosen by Mantell as lectotype of *Amm. varians*, even if he was unaware of having done so. At the same time, it is true, he created a var. *intermedia* for this "usual form of the species", but this was not considered to be a nomenclatorial irregularity in Mantell's time. Since the original of Sowerby's fig. 5, however, is closer to the smooth variety (var. *subplana* of Mantell) than to an original example of the same author's var. *intermedia*,[2] it is probable that Mantell had not seen Sowerby's example but was dependent on the figure. I may add that this illustration, like all the others, is not very accurate, if the specimens from the Sowerby Collection, listed by Crick as the five syntypes, really are the originals.

Unfortunately neither the restricted *Amm. varians* of Mantell, nor that author's own example of the var. *intermedia* agrees with Sowerby's original description, being neither "thickish" nor having a "roundish" aperture. It is clear, therefore, that what Mantell renamed var. *tuberculata* really represents the true *Amm. varians*; and that a lectotype has to be chosen from among the first four specimens figured by Sowerby. The obvious choice is fig. 1 (upper figure) which is wrongly drawn only in as far as it shows an umbilicus of about 33 per cent of the diameter, instead of 28 per cent, and the original of which is in a better state of preservation than the almost identical but more trituberculate example illustrated in fig. 2 (largest figure).

Now in the same year (1822) Brongniart,[3] without knowing of Mantell's var. *tuberculata*, created the new species *Amm. coupei* for the same form, while figuring as *Amm. varians* a compressed form for which de Haan[4] proposed still another specific name, *Amm. brongniarti*. The original *Amm. coupei* is small and difficult to appraise, but if it agrees (as seems probable) with the larger, but quadrituberculate form figured by Sharpe[1] as the commonest variety of this form, then Brongniart's species falls into the synonymy of *Amm. varians* as much as Mantell's var. *tuberculata*.

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[1] *Fossils of the South Downs*, 1822, pp. 115–17, pl. xxi, figs. 2, 5, 7.

[2] The larger specimen (fig. 7) is lost, so that the smaller example (fig. 5) in the British Museum (No. 33547) is chosen as lectotype of *S. intermedia*. It differs from the *Amm. varians* figured by Schlüter ("Cephalopoden der oberen deutschen Kreide," *Palaeontographica*, xxi, 1871, pl. iv, figs. 11–12 only) chiefly in being smaller and less strongly ornamented on the earlier half of the last whorl.

[3] In Cuvier and Brongniart, *Description géologique des Environs de Paris*, 3rd ed., 1822, p. 391, pl. vi, figs. 3 A–C.

[4] *Monographiae Ammoniteorum et Goniatiteorum*, Lugduni Batavorum, 1825, p. 121 (No. 42).

Semenow included Sharpe's example just cited in his *Schloenbachia sharpei*; but it differs sufficiently from the lectotype of that species (Semenow's pl. ii, fig. 9) for the latter to be retained as an independent form. Semenow's *S. coupei*, on the other hand, is identical with Sharpe's *S. inflata* (= *S. ventricosa* Stieler)[2] while Semenow's *S. tuberculata*, differing from Mantell's form (i.e. the true *S. varians*), had to be renamed (*S. trituberculata* Spath).[3]

In 1828 J. de C. Sowerby[4] figured and described as *Amm. tetrammata* still another tuberculated species of *Schloenbachia*. D'Orbigny already characterized that form as "evidently an adult individual of *Amm. varians*", and this view can almost be endorsed at the present day. The holotype of *Amm. tetrammata* seems to be lost, but the metatype (Mantell's specimen) mentioned by Sowerby is before me (B.M. No. 43964) and although it is slightly more inflated than the lectotype of *S. varians*, and therefore is somewhat transitional to the far more extreme *S. inflata*, it can hardly be separated as more than a variety. On the other hand Sharpe's[5] largest example of *Amm. coupei*, which was wrongly included by Semenow in his *Schloenbachia sharpei*, is another such intermediate form, like the metatype of *Amm. tetrammata*; while having a greater whorl-thickness in the earlier stages it retains throughout the ornamentation of the true *S. varians*, as now understood, and may thus be taken to be a typical example of the var. *tetrammata*.

Sharpe, the next reviser of the species under discussion, included in it only the lower figures (5 and 6) of Sowerby's plate, but he could not have seen the original of fig. 6. This was much more correctly appraised by Mantell, as has already been seen, and is, in fact, even more inflated than *S. varians*. It is indistinguishable from the inner whorls of the metatype of *Amm. tetrammata*, above mentioned, and thus certainly quite different from the original of Sowerby's fig. 5, or from any of the varieties recognized by Sharpe.

The var. *subtuberculata* of Sharpe (pl. viii, fig. 5), which was described as "the common form of the species" and which was also taken by Stieler to be the typical *S. varians*, is probably identical with *Amm. brongniarti* de Haan. Since this name, however, being a rejected homonym (Article 36) can never be used again, the common form of *Schloenbachia* will henceforth be known as *S. subtuberculata* (Sharpe). The ammonite figured by Zieten [1] and copied by Buckland [2] (and wrongly recorded as from the Jurassic of Geislingen) is probably a badly drawn example of this typical species; and the apparent differences between Sharpe's figure (5) and d'Orbigny's idealized illustrations (figs. 3–4) are probably due to the artists' idiosyncracies or the mode of preservation. Semenow's [3] figured example of *S. varians*, however, is a transition to *S. intermedia* (Mantell), with scarcely tuberculate and rather closely-set primary ribs.

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[1] "Description of the Fossil Remains of Mollusca found in the Chalk of England: Part I. Cephalopoda," *Mon. Pal. Soc.*, 1853, pl. viii, figs. 2 a, b.

[2] "Über Gault und Cenoman-Ammoniten aus dem Cenoman des Cap Blanc Nez," *Neues Jahrb. f. Min.*, etc., 1922, ii, 31.

[3] *loc. cit.*, *Proc. Geol. Assoc.*, 1926, p. 430. I then interpreted *S. coupei* in Semenow's sense. *S. trituberculata* is connected with the typical *S. varians* and *S. tetrammata* by forms like Sharpe's fig. 2 (pl. viii) or Sowerby's largest syntype (fig. 2).

[4] *Mineral Conchology*, vi, 1828, 166, pl. dlxxxvii, fig. 2.

[5] *loc. cit.*, *Mon. Pal. Soc.*, 1853, pl. ix, figs. 1 a, b.

The form figured by Sharpe as var. *intermedia* differs from Mantell's type (B.M. No. 33547) in its open umbilicus and distinct (instead of almost effaced) ribbing. It probably includes the *Amm. varians* depicted by Quenstedt [4] and thence copied in Zittel's and other textbooks, and it has been renamed *S. subvarians* Spath.[5] On the other hand, Sharpe's var. *costata* (now *S. costata*) is a distinct form, while Stieler's var. *costata*, based on Quenstedt's form already cited, falls within my *S. subvarians*. The faintly ribbed *S. subplana* (Mantell), as figured in Sharpe, acquires distantly spaced and strong outer tubercles at rather an earlier stage than Mantell's type; in the average examples the nodes remain fine and the sides smooth to twice the size of Sharpe's figure. Sowerby's fig. 5 (left-hand lower figure) belongs to *S. subplana*, despite the misleading illustration, but Semenow's var. *subplana* has rather a wider umbilicus than the English examples.

A more recent reviser of *S. varians*, namely Stieler (1922), by including in it flat and smooth varieties as well as all the inflated forms which had previously been identified with *S. coupei*, did not simplify matters as much as he hoped. Stieler did not select a typical form, needlessly renamed the var. *inflata*, wrongly described as new a var. *costata*, and he suppressed the var. *intermedia*, but he recognized the close affinity of his var. *nodulosa* with the Hoplitids of the Albian (*Pleurohoplites*). I may add that Messrs. C. W. and E. V. Wright have now found *S. nodulosa* [6] and close allies or varieties in the *dispar* zone of Dorset, apparently together with *Pleurohoplites*, and this species thus is the earliest known form of *Schloenbachia*.

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[1] *Versteinerungen Württembergs*, 1830–4 (Stuttgart), p. 19, pl. xiv, figs. 5 a, b.

[2] *Bridgewater Treatise, VI: Geology and Mineralogy*, etc., ii (1837), 59, pl. xxxvii, figs. 9 a–c.

[3] *loc. cit.*, *Trav. Soc. Imp. Nat. St. Pétersb.*, 1899, pl. iii, figs. 4 a, b.

[4] *Die Cephalopoden*, Tübingen, 1846–9, pl. xvii, fig. 4.

[5] *loc. cit.*, GEOL. MAG., 1926, p. 81, and *Proc. Geol. Assoc.*, 1926, p. 430 (with vars. *aperta* and *densicostata*).

[6] Based on *Amm. varians* (*non* Sowerby) in Bronn, *Lethaea geognostica*, Stuttgart, 1851–2, pl. xxxiii, fig. 2, which is difficult to interpret by those who have not examined specimens, such as Stieler's types at Lille. Schlüter's small form (*loc. cit.*, *Palaeontographica*, 1871, pl. iv, figs. 3–4 only), though apparently different, well shows the peculiar hoplitid ornamentation of *S. nodulosa*.

The eleven species so far admitted (excluding *S. coupei*, *S. brongniarti*, and the vars. *tuberculata* and *ventricosa*), with *S. falcato-carinata* (Schlüter) and seven new forms named by the writer on previous occasions,[1] constitute the genus *Schloenbachia* Neumayr, 1875, emend. de Grossouvre, 1893, the genolectotype being *S. varians*, as now interpreted. Whether *S. viridis* Lasswitz,[2] and *S. tollotianus* Pictet [3] are additional forms or not can only be decided on examining the type specimens, but *Amm. cinctus* Mantell [4] and probably *Amm. vectensis* Sharpe [5] are malformations, like the *S. coupei* figured by Crick.[6] *Hystrichoceras* Hyatt, 1900,[7] is a synonym of *Schloenbachia*.

Igneous Rocks from the Abercorn and Kasama Districts, Northern Rhodesia.

By T. Deans.

THIS paper presents a brief outline of the geology of the area shown in the map, Text-fig. 1, and a petrographic account of a small collection (eighty specimens) of its igneous rocks. The area is centred about 60 miles south-south-east of the southern end of Lake Tanganyika, and midway between Abercorn and Kasama. It lies at the headwaters of the Chambesi River, the source, or one source, of the Congo, on the high plateau of Northern Rhodesia at an altitude of 4,000 to over 5,500 feet. There is as yet no literature dealing with the petrology of North-Eastern Rhodesia, and the Rhodesian Copper Belt is too far distant (over 300 miles) to allow of any useful comparisons at this stage. It is interesting, however, to compare the rocks of this area with those of the Lupa Goldfield (1) in Tanganyika Territory, some 120 miles to the north-north-east.

Rocks of several systems are represented in the area, but dominating the geology are the Kundelungu sedimentary rocks and the granites. The former consist of unmetamorphosed arkoses, sandstones, quartzites, and shales forming high scarp-bounded tablelands resting unconformably on a floor of granites in which

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[1] *loc. cit.*, 1926 a, b.

[2] "Kreide-Ammoniten von Texas," *Geol. Pal. Abh.*, N.F., vi, 1904, 246 (*S. varians* var. *viridis*).

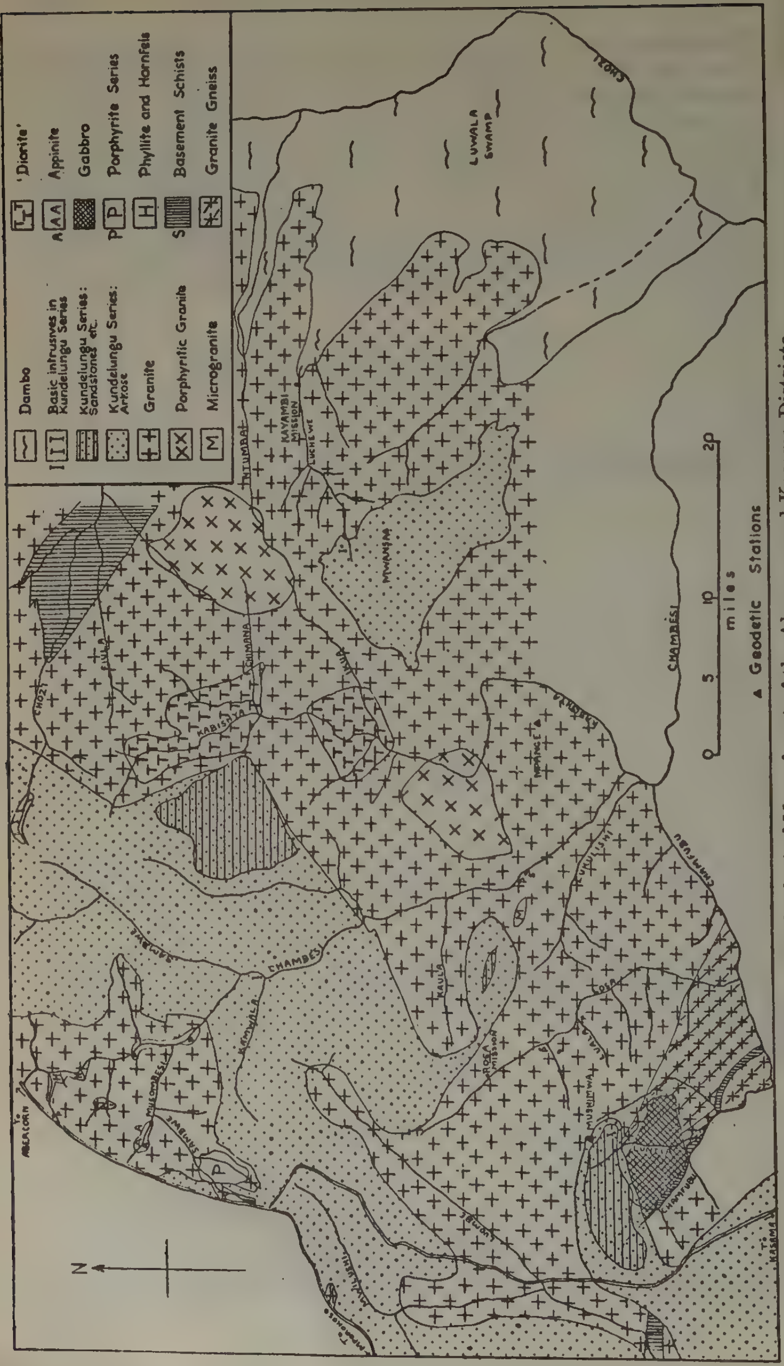
[3] In Pictet and Roux, *Description mollusques fossiles . . . grès verts*, 1847, p. 109, pl. x, fig. 5.

[4] In J. de C. Sowerby, *Mineral Conchology*, vi, 1827, pl. dlxiv, fig. 1.

[5] *loc. cit.*, *Mon. Pal. Soc.*, 1854, p. 45, pl. xx, fig. 4.

[6] *Proc. Geol. Assoc.*, xxix, 19, pl. ix, fig. A.

[7] In Zittel's *Text-Book of Palaeontology*, 1st English ed. (Eastman), 1900, p. 589.



TEXT-FIG. 1—Geological Map of part of the Abercorn and Kasama Districts.

small belts of older metamorphic rocks occasionally occur. The geological succession is tabulated below :—

System.	*Formation.*
	Regional quartz veins.
	Basic sills and dykes in Kundelungu.
Katanga System .	Kundelungu Series : arkoses with conglomerates, overlain by sandstones, quartzites, and shales.
	Major granitic and basic intrusions, and dolerites.
	Porphyrite Series.
	Phyllite and Hornfels Series.
Basement Complex	Basement Schists and Older Granite Gneiss.

Over much of the area shown on the map as " granite " outcrops are extremely rare and the soil covering very thick (its general thickness is unknown but it is certainly often over 30 feet). Further, the schists and other pre-granite rocks discovered were poorly exposed, and so it is probable that many more pre-granite rocks occur than are shown. The paucity of outcrops and the small number of specimens examined petrographically must be considered before basing any conclusions on the data presented here. The writer took part in the mapping of the area in 1936–7 on behalf of Loangwa Concessions (Northern Rhodesia), Ltd., to which Company he is indebted for permission to publish this paper.

I. THE BASEMENT COMPLEX.

Quartz-mica-schists and grits, extensively mineralized with tourmaline, striking between east-south-east and east-west, occur on the north bank of the Chamfubu, and where it is joined by the Luntia these are associated with hornblende-schists and gneisses. West of this is a large but poorly exposed area of gneissic granites and augen-gneiss referred to the Basement Complex, but these have not been examined petrographically. A small outcrop of quartz-mica-schists, striking south-east, similar to those of the Chamfubu, occurs on the west bank of the Chambesi almost due west of Mpange Hill. On the Luombe River west of Kaunguluka's village is a poorly exposed belt of interbedded mica-schists and quartz-schists, striking east-west. In the north-west corner of the area on the Chozi and Fiula Rivers are a wide range of Basement rocks including mica-schists and graphite-schists but these were not seen by the writer.

II. THE PHYLLITE AND HORNFELS SERIES.

These rocks occur in the stream joining the Chambesi from the west, four miles south of the Chambesi bridge,[1] and the phyllites also in the bed of the Kamaronge stream farther north. They strike south-east and are clearly invaded by the granite. The hornfels is exposed within 50 yards of the granite contact, and is a fine-grained quartz-biotite-cordierite-hornfels with plentiful plagioclase (andesine-oligoclase) and originally was presumably a greywacke. It is slightly mineralized with stringers of quartz, fluorite, epidote, and hornblende. The age of these rocks is uncertain, and they may belong to either the Muva-Ankole system or to the earlier part of the Katanga system (Mine Series).

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[1] Bridges referred to in this paper are all on the Abercorn–Kasama main road.

III. The Porphyrite Series.

Rocks of this series were found in five areas west of the Chambesi and it is probable that parts of the areas mapped as "diorite" on the Kabishya River should be assigned to it. They are presumed to occur as sills, but the field relations are not clear. In the field they are recognized by their green-tinged porphyritic felspars set in a green aphanitic groundmass, and when quartz phenocrysts are present they have usually a characteristic blue appearance. They range from granodiorite-porphyries to hornblende- and pyroxene-porphyrites, and are generally considerably altered, the plagioclase being saussuritized and secondary amphibole, epidote, and quartz appearing in the groundmass. The only evidence as to their age is that at one locality they are thermally metamorphosed by the granite. They may therefore belong to an earlier period of igneous activity, or to an earlier phase of the activity which culminated in the intrusion of the granites. The latter possibility is favoured by their similarity in composition to the granodiorite-appinite suite described below. The localities and rock types are :—

(i) An area of 6 square miles around the China and Sambwe streams east of the Chela Bridge. Hornblende-porphyrite is the dominant type, with quartz-porphyrite slightly less abundant. The former consists of altered plagioclase phenocrysts, 1 to 3 mm. across, small elongated prisms of brown hornblende, other ferromagnesian phenocrysts replaced by aggregates of green hornblende or chlorite and epidote, and iron-ore rimmed with granular sphene, set in a fine-grained microcrystalline groundmass. A distinctive accessory is dichroic smoky apatite in long prisms. The quartz-porphyrites contain phenocrysts of bipyramidal quartz, corroded and broken up by the groundmass which has penetrated them along cracks, zoned andesine phenocrysts and numerous small composite fragments of an earlier solidified phase of the same rock, set in a groundmass of devitrified glass with occasional spherulites. Dichroic smoky apatite is again present.

(ii) On the north side of the Kamaronge stream, $\frac{3}{4}$ mile downstream from the bridge. A granodiorite-porphyry has here been thermally metamorphosed by the granite. The strained bipyramidal quartz, zoned andesine phenocrysts and long dichroic smoky apatites are the same as in previous types, but the groundmass and ferromagnesian phenocrysts have suffered recrystallization. The latter are now represented by aggregates of small olive-brown biotite and a distinctly bluish hornblende (X greenish-yellow, Y olive-green, Z greenish-blue, $\gamma \wedge c$ 20°) in small flakes or with sieve texture, and a little tourmaline. The tourmaline indicates the introduction of boron from the granite, and is an iron-rich type, being deeply coloured, with a purplish-brown and a very dark brown giving almost complete absorption. Long streaks of small flakes of biotite run through the groundmass in curving lines and give the rock a striking appearance. They are perhaps due to recrystallization along cracks or flow lines.

(iii) In the Chambesi dambo a mile north of where the river cuts through the arkose (Kundelungu) escarpment. These are somewhat coarser and more acid in the groundmass than the previous types, and may be considered as transitional towards granodiorite. Some are intensely sheared, the strike of the shearing being east-west, while others show no strain effects. The phenocrysts are of basic andesine, showing pronounced oscillatory zoning, and the ferromagnesian phenocrysts are altered to an aggregate of pale hornblende surrounded by small greenish biotites with prehnite developed in the cleavage planes. The groundmass is rather coarse and contains quartz, some of which is secondary, being associated with acicular actinolite. Flow structure is often discernible.

(iv) On the Luala and Nambusa streams, tributaries joining the Losa River from the west. Acid types with quartz phenocrysts occur on the Luala, but on the Nambusa the rock is a pyroxene-porphyrite with phenocrysts of fresh twinned diopside and bastite pseudomorphs presumably after rhombic pyroxene. The plagioclase phenocrysts are completely replaced by epidote and sericite. The groundmass consists of altered felspar laths, fresh augite, quartz, iron-ore, and secondary chlorite and epidote.

(v) Forming rapids on the Chambesi River almost due west of Mpange Hill is a series of porphyritic rocks, strongly sheared in an east-south-east direction, and often pyritized. They are associated with Basement Schists and their strongly sheared condition suggests that they may be older than the porphyrites described above, but provisionally they have been mapped as such. Unfortunately specimens are not available.

IV. THE GRANITES AND ASSOCIATED INTRUSIVES.

The granites suffered considerable denudation before the deposition of the Kundelungu arkoses on their peneplained surface, which was subsequently warped into broad folds. Recent denudation has done little more than uncover this old peneplain. Irregularities in the peneplain surface are rare, but in the escarpment at the east end of Mushimwa Hill a small knob of granite cut by a dolerite dyke rises into the arkose, and the contact, although obscured by a few feet of scree, is clearly an erosion surface. The deep erosion of the intrusions in pre-Kundelungu times accounts for the notable rarity of such marginal and roof features as fine-grained modifications, pegmatites, xenoliths, and pneumatolytic minerals, and the limited variation of the rock types. The mutual relations between the various intrusions are seldom apparent, outcrops being so scattered.

The majority of the granites are clearly to be correlated with the "Younger Granites" G 3, 4, and 5 of Tanganyika (2), but the term is not used here as its meaning in Northern Rhodesia is not clear. Bancroft and Pelletier class the "Younger Granites" as pre-Kundelungu (3), and Hennig adopts this view in his correlation table (4), in agreement with East African usage. On the other hand, Jackson found that in the N'Changa district they may be in part at least post-Kundelungu (5), and more recently Hatfield has produced a correlation table in which they are referred to the Karroo (6).

(*a*) GRANITES AND DIORITIC ROCKS.

(i) *East of the Chambesi River.*

In an area 10 miles east of Kayambi Mission, about 2 to 3 miles north and south of the Ntumba stream, are a few small exposures of biotite-microcline-adamellites. North of the Ntumba the rocks are unfoliated, but south of it they show a persistent south-east foliation. The felspars are microcline and oligoclase, the latter usually sericitized and containing small epidote crystals. The biotite is brown and noticeably fresh, and contains none of the inclusions of secondary products which characterize most of the granites described below. Sphene, magnetite, epidote, apatite, and orthite are accessory.

A large mass of porphyritic granite some 6 to 8 miles across occurs at the headwaters of the Ntumba, Ikua, and Chimana streams. The large felspars, often one to two inches in length, are orthoclase. The granite base consists of quartz, microcline, idiomorphic albite, with chequer inclusions of quartz, and also clinozoisite and epidote. The biotite is greenish brown, and accessory apatite, magnetite, and sphene occur.

Two specimens from the surrounding non-porphyritic granites are adamellites of allotriomorphic texture. They consist of microcline or perthite, acid plagioclase, sericitized, often in chequered patches, and green-brown biotite containing secondary prehnite and epidote developed along the cleavages, a little green hornblende and accessory epidote, sphene, apatite, magnetite, and occasionally zircon.

(ii) *West of the Chambesi River.*

A. In the triangular area south of the Chambesi bridge between that river and the road, and bounded on the south by the Kundelungu escarpment, the dominant type is granodiorite with subordinate related diorite, and appinite.

The granodiorite consists of quartz, anhedral microcline, abundant idiomorphic oligoclase-andesine, usually sericitized, and both biotite and hornblende, the former usually but not always dominant. The biotite is greenish-brown and always has secondary products developed along the cleavage planes—separated from it during paulopost reactions. Prehnite is the commonest of these, and sometimes the biotite is completely replaced by an aggregate of prehnite and chlorite of the penninite group. Another mineral developed in the biotite at this stage has not been identified, although it occurs in many British granites. In thin section it appears as rather fat colourless spindles in the cleavage planes, with high refractive index (above 1·77), and very low birefringence, and always positive elongation. Its refractive index appears to be too high for the epidote group. Accessory iron-ore, epidote, orthite, apatite, and sphene occur, and secondary chlorite and prehnite.

Appinite forms a mass a mile in length and half a mile wide on the Musombesi River, 1½ miles downstream from the bridge. In hand specimen the rock is seen to consist of 50 per cent of stumpy prismatic crystals of dark green hornblende about 1 cm. across, set in a dark green groundmass with scattered but noticeable patches of quartz and pink felspar. It could be matched almost exactly among the Scottish appinites. Microscopically the hornblende of the phenocrysts is pleochroic on the scheme X yellow, Y olive-green, Z bluish-green, with $\gamma \wedge c$ 26°, and γ about 1·672. It frequently shows twinning and in places is bleached, and sometimes encloses aggregates of prehnite and chlorite. In the groundmass the hornblende occurs as tiny idiomorphic crystals, and also as ragged aggregates associated with much prehnite, epidote, and chlorite, and very occasionally with augite cores. The plagioclase is subhedral and around andesine and andesine-oligoclase, often showing sericitized cores and fresh margins. Microcline, although conspicuous in hand-specimen on account of its pink colour, is very subordinate in thin section. Both the microcline and quartz occur as large crystals poikilitically enclosing the hornblendes. There is abundant accessory sphene and apatite in large crystals.

On the north side of the Musombesi at the eastern end of the appinite mass and clearly related to it is a hypersthene-quartz-diorite. The felspar is entirely plagioclase and forms zoned phenocrysts of andesine-oligoclase, and in the groundmass laths of andesine-labradorite. Interstitial quartz is fairly abundant. Faintly pleochroic hypersthene is abundant and is rimmed with green hornblende in parallel orientation. Colourless diopside-augite ($\gamma \wedge c$ 44°) occurs as irregular grains and shows more advanced conversion to hornblende than the hypersthene. Reddish-brown biotite occurs as scrappy flakes, some including secondary prehnite. Apatite and magnetite are accessory.

In Tanganyika appinites are a characteristic feature in the Lupa Goldfield, and they are also reported from other districts (2). While generally similar, this example differs from those of the Lupa in the absence of diopside and the association with hypersthene-quartz-diorite.

In the Sambwe stream, a mile above its confluence with the

Musombesi, there occur gneissic biotite-granites which appear to be older than the granodiorites of this area. They are fine-grained rocks of adamellitic type, with granulitized quartz, large saussuritized plagioclases, and clear microcline-perthite and oligoclase among the granulitized base. The biotite is greenish, partly altered to chlorite and with secondary prehnite and yellow epidote relegated to the cleavage planes. Secondary sphene with sieve texture is noticeable, and apatite, iron-ore, and orthite are accessory.

B. In the Luombe valley close to its source there occur fresh rather melanocratic adamellites. A mile below where the telephone line crosses the Luombe is a pinkish porphyritic biotite-adamellite. It consists of twinned phenocrysts of orthoclase about half an inch long, idiomorphic altered plagioclase, perthitic orthoclase, quartz, and altered greenish biotite with abundant secondary inclusions of strongly coloured epidote (yellow-green), the undetermined mineral described above, and sphene. Iron-ore, apatite, sphene, and orthite are accessory.

Biotite-hornblende-adamellite occurs near Yombe's Village, the hornblende showing occasional cores of diopside, and the biotite again the secondary minerals, including prehnite, in the cleavage planes.

Farther downstream, below Chondu's Village, is a biotite-diopside-granite. It consists of quartz, abundant orthoclase, idiomorphic andesine, and calcic oligoclase, biotite, diopside, hornblende, and the usual accessories. The biotite is fresh, reddish-brown, but in places encloses secondary sphene and the undetermined spindles. Colourless diopside is abundant, occasionally idiomorphic, but usually rimmed or patchily replaced by green hornblende.

C. On the Luombe River for 7½ miles below the bridge the granites are well exposed. Granodiorite is predominant, with adamellites and tonalites. Some are gneissic with foliation trending east-south-east, others apparently unfoliated, but in thin section all show granulitization or other strain effects. The adamellites contain microcline and idiomorphic acid oligoclase. In the granodiorites there is a little orthoclase and the plagioclase is very decomposed, but in the tonalites, which are rather melanocratic, the plagioclase is andesine. The biotite is always greenish-brown, with secondary spindles of prehnite, the undetermined mineral, and epidote, and is often replaced by penninite. Idiomorphic green hornblende may be abundant. Pale epidote in large grains around hornblende and iron-ores is rather common, and as accessories large sphenes, apatite, orthite and zoisite occur. One granodiorite-gneiss contains minute veinlets of prehnite and epidote, in addition to prehnite and penninite presumably after biotite.

D. In the area between the road and the Chamfubu River east of Ngoli's Village are isolated outcrops of micrographite of the alkali-granite family. They are leucocratic rocks, consisting of quartz, microcline or orthoclase, and albite in micrographic intergrowth, with porphyritic albite and quartz, and much muscovite. There is a little biotite, usually replaced by greenish-yellow chlorite, and finely granular magnetite and epidote.

E. Ten miles east-south-east of Rosa Mission, at the head of the Chipanga stream and forming the hills behind Chombe's Village, is a mass of very fine-grained microgranite. It is clearly a hypabyssal mass but there is no evidence as to its age or relations to the other intrusives. In thin section it shows a very close resemblance to the Threlkeld microgranite of Cumberland. It consists of quartz, orthoclase, and albite, and a little green chlorite, of grain-size between 0·1 and 0·05 mm., with occasional phenocrysts of albite and quartz 0·5 to 1 mm. in size.

(*b*) GABBROS.

(i) *The Luntia Hypersthene-Gabbro.*

This is the only large basic mass in the area, having an exposed area of 18 square miles, and its north-western limits concealed beneath the Kundelungu arkose. In places it is strongly sheared, as is well seen in the Kapato dambo, and in thin section strain effects are always evident. It is a rather fine-grained grey or green rock, usually with a brownish tinge imparted to it by the hypersthene. The typical fresh rock contains about equal amounts of plagioclase and pyroxenes. The plagioclase is labradorite ($Ab_{40}An_{60}$) and occurs in equidimensional grains with dark saussurite clots and shows a faint but distinct clouding which reveals the twin lamellae in ordinary light. The crystals are frequently bent. The pyroxenes are hypersthene and diallage in variable proportions but often in equal amounts. The hypersthene occurs in large plates, distinctly pleochroic from pink to greenish-grey, with schiller inclusions and poikilitic inclusions of plagioclase. It is often bent and then shows a very fine lamellar striation suggestive of twinning and occasional narrow lamellae which appear to be parallel intergrowths of augite. The clinopyroxene is schillered diallage ($\gamma \wedge c$ 48°) in ragged plates. There are small scraps of red biotite which have sometimes a tendency to be in parallel intergrowth with both pyroxenes, and a little apatite and pyrite.

In a type altered presumably by paulopost changes the pyroxenes are completely replaced by aggregates of pale uralite, and zoisite is developed and there is much pyrite. The plagioclase in this rock is labradorite in large twinned plates, but there is also much granular untwinned bytownite.

An acid phase from the south-east margin of the mass contains the hypersthene and diallage of the normal rock, together with abundant quartz and red biotite, the latter with prehnite inclusions.

(ii) *Minor Occurrences.*

Few specimens of the several minor occurrences have been examined. There is a small outcrop of rather fine-grained hypersthene-quartz-gabbro where the Luchewe stream leaves the arkose plateau. It consists of large plates of hypersthene replaced partially by chlorite, in a base of labradorite and fresh augite, with areas of granophyric quartz and orthoclase associated with chlorite and calcite.

Near the source of the Ikua stream is a small gabbro mass which contains scapolite. Two rock types occur together. The one is a quartz-gabbro containing abundant phenocrysts of plagioclase up to 1 cm. across. The latter show a core broken down to sericite and epidote rimmed with clear labradorite. The groundmass consists of labradorite laths, augite, a little interstitial granophyric material and accessory skeletal ilmenite, biotite, and apatite. The second type is a fine-grained rock containing numerous "nodules" of coarse plagioclase and augite up to an inch in diameter. Microscopically it has a variable texture, in places showing parallelism of plagioclase laths, suggesting flow-structure, elsewhere being coarser grained. Mineralogically it resembles the previous type but contains few plagioclase phenocrysts and little quartz. The "nodules" consist of large crystals of altered plagioclase, augite in slightly less amount, and chlorite and a little pyrite. There is no evidence as to their origin, but it would seem most likely that they are xenoliths. Their boundaries are irregular, but there is no evidence of reaction between them and the surrounding gabbro. A little unaltered plagioclase, determined as calcic labradorite (γ 1·570), remains, but the greater part is now replaced by scapolite crowded with inclusions of sericite. The scapolite forms broad lamellae and appears to be a mizzonite about $Ma_{35}Me_{65}$ (ω 1·585 to 1·590). The augite is quite fresh and appears to be a diopsidic variety (α' 1·68). The chlorite is a rather highly birefringent variety, also met with in some of the dolerites of the area, optically negative, with γ 1·627, birefringence about 0·012 and X yellow, Y and Z green. From Winchell's diagram it would appear to be near to ferroantigorite. This is the only occurrence of scapolite noted in the area, and it is clear that the widespread regional scapolitization met with in North-Western Rhodesia (5, 6, and 7) is not present here. An unusual feature of this case is the unaltered condition of the augite associated with the scapolitized plagioclase.

(*c*) DOLERITES.

Dolerite dykes, and probably also sills, are numerous in the area, particularly in certain parts, but they have been omitted from Text-fig. 1 to avoid overcrowding. The majority cut the granites, but are referred to the same general period of igneous activity. Where the strike is discernible it usually follows the regional trend varying between south-east and east. Quartz-dolerites are the commonest type. In these granophyric quartz and orthoclase is usually conspicuous, the quartz including fine rods of apatite, and skeletal iron-ore is characteristic. Chlorite, prehnite, and calcite are late-stage minerals, and large bastite pseudomorphs, presumably after hypersthene, are present in some.

Normal dolerites occur and grade into completely uralitized types, often veined with epidote, chlorite, prehnite, or quartz. Occasionally they are porphyritic with phenocrysts of either labradorite or augite. In two cases, one a quartz-dolerite, the other a normal dolerite, the distinctive yellow-green highly birefringent chlorite described above in the scapolitized rock, occurs in the rather anomalous manner as cores within augite.

V. THE KUNDELUNGU SERIES.

This series is quite unmetamorphosed and is clearly a different facies from its equivalents in the Copper Belt and North-Western Rhodesia where they were involved in geosynclinal downfolding and regional metamorphism. The lower part of the series consists of purple arkoses, frequently cross-bedded, with conglomeratic bands at several horizons, but without any distinct basal conglomerate. Overlying these, in apparent conformity, are sandstones, quartzites, shales, and mudstones, with occasional cherts, exposed in the synclinal basins shown on the map, and to a wider extent farther south where they extend in an east-west belt through Kasama, disappearing to the south below the flats of the Chambesi. No fossils were discovered in this area, but microscopic algae are reported from Mpulungu (8) only 35 miles north of the boundary of the map. To the north the series continues into Tanganyika as the Kasanga beds referred to the Bukoba System (2), and westwards they extend to Lake Mweru (9), and thence south into the Kundelungu Plateau of the Katanga.

VI. BASIC INTRUSIVES IN THE KUNDELUNGU SERIES.

A dolerite sill outcrops for 4 miles in the Kundelungu arkose at the source of the Chozi River, and a smaller quartz-dolerite sill was discovered in the overlying sandstones south of the area shown in the map, just west of Kaseshya Hill. Of more frequent occurrence are very thin and completely altered sills and dykes. Several thin dykes occur in the arkose crags at the head of the Luchewe stream. One, 18 in. wide, is a minutely vesicular variolite, altered completely to sericite and fine hematite, with an almost opaque tachylitic margin. Two miles south of Mushimwa Hill, in the quartzites, the ground is strewn with fragments of pinkish to grey rocks with clayey fracture, which would naturally be taken for mudstones. In section, however, they are completely sericitized but show the outlines of felspar laths and conspicuous vesicular texture, replaced to various degrees by hematite. Their original composition remains unknown, but as quartz is absent they were probably basic. In form they were probably sills. South of the map, at the head of the Kawenko and Chipato streams 40 miles east of Kasama, similar rocks are exposed as thin sills in a shear zone in the sandstones. Brown seriticized types are typical, but compact green cores reveal chloritic rocks with secondary quartz and leucoxene and a tendency to variolitic texture. These were perhaps of the composition of quartz-dolerites.

VII. THE REGIONAL QUARTZ VEINS.

A regional system of giant quartz veins cutting all formations, although best developed in the granites, is a conspicuous feature of the area. Mpange and Panya Hills may be cited as two spectacular examples, forming hills of glistening white quartz rising out of the flat bush-covered granite country. The largest *single* vein seen by the writer was that of Panya Hill, 13 miles north-west of Kayambi Mission, which is 1½ miles long and ¼ mile wide. Single vein-systems are frequently continuous for up to 16 miles, and consist of individual veins from 200 yards to a mile or more in length and usually from 10 to 100 yards in width, lying *en échelon*. The strike of the veins is persistently east-south-east, the only exceptions being in a north-south belt running through the Mwansa arkose outlier, where exceptionally large veins occur, e.g. Panya and Mulembe Hills, running north-south. Internally, however, these veins show a south-east strike of the individual stringers of the multiple vein. The veins consist of white quartz ranging from coarsely crystalline to cherty, the only associated mineral being occasional specular hematite in veins in the arkose. Brecciation is typical, being particularly pronounced in the arkose.

There is no evidence within the area to determine the age of these veins, but presumably they originated during a period of major earth movements, which suggests the possibility of their belonging to the Rift Period. It would be interesting to endeavour to trace these veins into an area of rift movements.

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REVIEWS.

SHREWSBURY DISTRICT, INCLUDING THE HANWOOD COALFIELD. By R. W. POCOCK, T. H. WHITEHEAD, C. B. WEDD, T. ROBERTSON, with contributions by D. A. WRAY, C. J. STUBBLEFIELD, T. C. CANTRILL, and W. M. DAVIES. *Mem. Geol. Survey*, pp. xii + 297, with viii plates and 33 text-figs. 1938. H.M. Stationery Office. Price 5*s*., postage extra.

THIS long awaited and very welcome Memoir of the Shrewsbury District deals with the geology of rocks ranging in age from pre-Cambrian to Bunter, as well as with the superficial deposits. The chapters on the Uriconian and Longmyndian rocks afford interesting reading, and the introductory account to the pre-Cambrian can be specially recommended for its well-reasoned and balanced presentation of the difficulties encountered when considering the relative ages of the pre-Cambrian subdivisions in Shropshire. The application of the differences in dips measured in the competent and incompetent beds of the same major fold to the determination of the order of superposition shows that the westerly dips in the Western Longmyndian are inverted ; on the other hand, it may be added that wherever the present writer has seen fracture cleavage developed in the Eastern Longmyndian the evidence indicates that the westerly dip of the rocks is normal. Our information now seems to suggest that the ascending sequence in the Western Longmyndian is in the opposite direction to that of the Eastern Longmyndian. Two of the major problems which await solution are the age relationships of the Eastern and Western Longmyndian, and the explanation of the reversed dip in the latter and how this can be fitted into the general tectonic structure of the Longmynd. In deference to Dr. Cobbold's researches it should be mentioned that he had long ago discarded his hypothesis that if the base of the Llandovery on the eastern flank of the Longmynd were tilted back to a horizontal position, then the Eastern Longmyndian, which has a high westerly inclination, would assume an easterly dip ; Llandovery rocks also occur on the western flank of the south-west spur of the Longmynd and if the same reasoning were applied here the Eastern Longmyndian rocks would still possess a westerly dip. The conflicting results were obtained because the varying directions of dip in the Llandovery sediments are largely controlled, not by tectonics, but by changing direction of the trend of the shoreline.

Many geologists will regret that the informative chapters on the Older Palaeozoic rocks had to be abridged, for it is certain that the descriptions in the original manuscript would have contained additional and valuable information. It is true that many details of the Cambrian and Silurian stratigraphy have already appeared, but the important Ordovician succession of the Caradoc region is worthy of more extensive treatment, and it is a disappointment that full field observations and palaeontological data are not available in the Memoir. The Hoar Edge Group is one of the more attractive of the Caradoc subdivisions, for not only do the rocks show a reduction in thickness and a lithological change from grits to calcareous sandstones when traced north-eastwards along the strike, but the grit has yielded wind faceted pebbles.

In the Coalbrookdale Coalfield the abbreviated succession of the Carboniferous Limestone, referable to the Dibunophyllum Zone, is succeeded unconformably by the Middle Coal Measures; in the Shrewsbury Coalfields only Upper Coal Measures are developed, and of the divisions recognized in North Wales or the Midlands only the Coed-yr-Allt Group and the Erbistock Group have been determined within the boundaries of Sheet 152. The concluding chapters of the Memoir are devoted to glacial and post-glacial deposits, and to economic resources including mineral products, water supply, roadstones, and other items. Among the appendices are contributions on soil and agriculture, and on age-determinations by the helium method of the Little Wenlock and Clee Hill basalts.

W. F. W.

CORRESPONDENCE.

ASHDOWN SAND—WADHURST CLAY JUNCTION.

Sir,—In consultation with members of the Weald Research Committee (Geologists' Association), I am investigating in detail the Ashdown Sand—Wadhurst Clay Junction in a part of the Weald, and hope to extend my work throughout the area. I am communicating with you in the hope of avoiding unnecessary duplication of this work by others, and to put on record a few points which I have already established. Most of the localities already studied are on the 6 in. sheets 44, 45, and 58.

The topmost few feet of the Ashdown Sand are usually horizontally bedded and may contain a small percentage of glauconite and a Brittany suite of minerals. They are always found to be capped by a highly current-bedded series of grits or conglomerates. These indicate a phase quite distinct from that below (e.g. they overstep the occasional oblique beds of the lower phase in deltaic fans). Their upper surface (on which the lower Wadhurst shales rest) is ripple-marked with the ripples normally aligned in a N.E.–S.W. direction.

The basal Wadhurst shales and siltstones exhibit certain distinct and fairly widespread phases :—

(1) The lowest phase is a bone-bed containing *Hybodus* and *Lepidotus*, well exposed in the neighbourhood of Brede. (2) A beautifully developed *Equisitites* sp. " marsh ", in which all the specimens are in a vertical posture, occurs also in the lowest foot. The species closely resembles *E. lyelli*, but is much smaller, and is not referable

to *E. burchardti* described by Seward, because of the greater number of scale leaves at each node. This marsh has already been mapped over an area of 12 square miles with a length of at least 6 miles. Its N.E., E., and S.E. boundaries are not yet fully ascertained, for there the horizon becomes sandier and the marsh fades out. (3) Above this bed, and partly intermingled, is a layer of *Equisitites lyelli* (Seward) often packed with large specimens lying horizontally. Whether this represents a wrecked marsh or drifted material is still uncertain. Its known extent, at present, is about 11 square miles. (4) A shelly bed (3 inches of smashed *Cyrena* shells) supervenes in one district, and this has been traced along an apparently restricted belt for 1½ miles. (5) In the sandier facies about Rye and Fairlight, where the lower marsh is not found, less sandy conditions developed later and brought with them the *Equisitites* " marsh " for the first time at a horizon 2 feet above that of its occurrence in Brede. By that time it had probably disappeared in the west and north. (6) In several localities the shales are succeeded by a thick series of sandstones full of casts of *Cyrena*, with bands of Tilgate stone capped by another bone-bed in Brede. This is very distinct from the lower one in its greater faunal variety (*Hybodus*, *Lepidotus*, *Tretosternum*, *? Iguanodon*, *Goniopholis*, *Cyrena*, plants) and in its conglomeratic character. I have little doubt that it is this bed which is of the same age as the Battle, Crowhurst, and Hollington occurrences. (7) The succeeding 9 feet of siltstones and shales may include a second *Equisitites* " marsh " with nine shelly bands and a third (shelly) bone-bed (*Lepidotus* and *Hybodus*). The top of this is certainly less than 25 feet above the Ashdown grits.

PERCIVAL ALLEN.

DEPARTMENT OF GEOLOGY,
THE UNIVERSITY, READING.
17th October, 1938.

REPORTS AND PROCEEDINGS.

MINERALOGICAL SOCIETY.

3rd November, 1938.

(1) " On an example of α-quartz showing good cleavages parallel to the three prism-faces." By Dr. J. Drugman.

(2) " On an example of α-quartz crystals with a steep rhombohedron as predominant form." By Dr. J. Drugman.

(3) " The relation of stellerite and epidesmine to stilbite." By Dr. A. Pabst. (Communicated by Mr. F. A. Bannister.)

It is shown that stellerite and epidesmine are varieties of stilbite which, though truly monoclinic, are both optically and morphologically pseudo-orthorhombic. A new analysis of stellerite-like stilbite is reported.

(4) "The adinoles of Dinas Head, Cornwall." By Mr. S. O. Agrell.

Adinoles associated with spilosites and spotted slates occur at the contact of an albite-dolerite intrusion with black limestone-bearing slates of Upper Devonian age. Four main types are recognized.

1. Normal adinoles—grading into rocks composed essentially of dravite.
2. Adinoles with pseudomorphs probably after andalusite.
3. Adinoles with globular masses of ankerite showing concentric structures.
4. Polygonal and spherulitic adinoles.

Chemically, the adinoles resemble quartz-keratophyres and their tuffs but the evidence at Dinas Head shows that they are due to the effect of the intrusion on the sedimentary rocks. The first change was purely thermal and was followed by albitization and then by carbonatization, the metasomatizing fluids coming from the dolerite.

(5) "On three australites of unusual form." By Mr. F. A. Singleton. (Communicated by the General Secretary.)

The paper describes a Tasmanian button form with an exceptionally broad translucent flange; a New South Wales aberrant canoe form in which the normal sculptures of the two surfaces are not differentiated; and a South Australian button core which is hollow and translucent.

(6) "Merosymmetry versus Merohedrism." By Professor Austin F. Rogers.

It is often convenient to refer to classes with varying degrees of symmetry within a crystal system and for this purpose the terms holohedral, merohedral, etc., are usually employed. Reasons are given for preferring the suffix -symmetric to the suffix -hedral, thus giving holosymmetric, merosymmetric, etc. These terms were introduced by Story-Maskelyne in 1875, but his nomenclature was unnecessarily complicated.

A simple set of names based upon merosymmetry is presented as a list supplementary to the class names based upon general forms. Since there are only six crystal systems, if we employ that term in the usual sense of a series of closely related classes with geometrical and physical properties in common, there are only six holosymmetric classes.

(7) "Zoned olivines and their petrogenetic significance." By Dr. S. I. Tomkeieff.

The composition of zoned olivines as determined by measurements of the optic axial angle shows a relation between the olivines and the composition of the parent rocks. Within the olivines the variation is from a Mg-rich centre to a Fe-enriched margin.

(8) "The crystallography of sartorite." By Mr. F. A. Bannister, Dr. A. Pabst, and Mr. George Vaux.

The complex forms of this mineral like those of calaverite have in the past been indexed by various expedients not mutually consistent. Laue and rotation photographs reveal that sartorite is monoclinic β 90° with a 58·38, b 7·79, c 83·3 Å containing 240 $PbAs_2S_4$ and that it possesses a well-marked orthorhombic pseudo-cell with a 19·46, b 7·78, c 4·17 Å. The abundant measurements made by previous crystallographers can be interpreted satisfactorily on the basis of our X-ray measurements.

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